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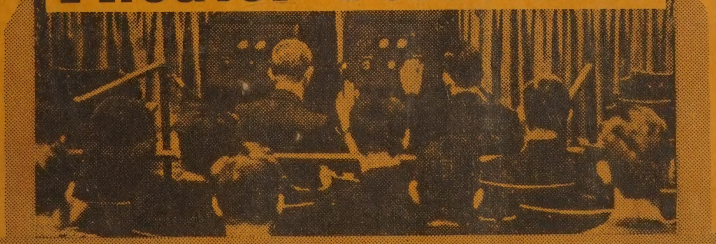
FOR BEGINNERS

Theater Television



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TELEVISION FOR BEGINNERS

Theater Television

By JAMES R. CAMERON

Fellow, Society of Motion Picture Engineers, Member, Institute of Radio Engineers, Acoustical Society of America, etc., etc.

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HISTORICAL

Television research was practically at a standstill between 1847 and 1873, when due to the discovery of selenium, the element on which our first photo-electric cells depended, new life was given the subject, with the result that in 1878 M. Senlecq introduced the "Telectroscope."

The Telectroscope was patterned along the lines of Caselli's apparatus except that Senlecq used the newly discovered selenium as the operating device.

In 1880 Professor Kerr and Graham Bell were granted several patents pertaining to television. Kerr's system making use of a multiple of selenium cells.

In 1884 the German inventor Nipkow conceived the idea of television by using a scanning disc, he was greatly handicapped in his experiments due to not having the proper type of light cells to work with, selenium having been found to respond too slowly. His method of scanning the picture is the basic principle on which most of the commercial television sets of today depend.

Rignoux and Fournier two names long connected with television research, early suggested a method, where a surface studded with thousands of "eyes" in the form of selenium cells, each cell directly connected to an individual circuit was expected to build up a picture. The idea being that each cell would transmit a different light intensity, a similar arrangement being responsible for the transmission of the picture from the studio. A similar idea was suggested by C. Francis Jenkins in an article appearing in the *Electrical Engineer* of July 25th, 1894.

Another step forward in television history was made, when Rosing in 1907 made use of the cathode ray.

Rosing's Cathode Ray

Boris Rosing's receiving set brought the cathode ray into television.

When electricity at a very high voltage is passed through a vacuum, an electrical discharge takes place and this has been termed the cathode ray. These rays can be produced in a very fine light beam and can be rendered visible if projected onto a suitable screen.

This ray can be diverted from its path, either electrically or mechanically, and there is no known limit as to the speed at which it can be moved around.

Fig. 13. At his transmitter he used two mirror polyhedrons revolving at right angles to each other, as shown in the diagram at C and D. As in the case of Szczepanik's vibrating mirrors, one mirror polyhedron revolves much more slowly than the other. The combined motion of these mirrors causes an image of the object to be transmitted, A (focussed on to C through the lens B), to be swept across the aperture of the selenium cell, H.

The varying current impulses from the cell, H, are transmitted to the receiver, where they are caused to charge two condenser plates, L, in the cathode ray tube. The fluctuating charge impressed on these condenser plates produces electrostatic stresses which cause the cathode ray beam to be deflected away from the aperture, M, placed in its path, and the amount of the ray which passes through the aperture is thus made proportional to the potential of the plates, *i.e.*, to the degree of light and shade in the original scene.

Having got through the aperture, M, the ray then strikes the fluorescent screen, N. The manner in which the ray is caused to bend to and fro, thus covering the entire screen, is quite ingenious.

The revolving mirror polyhedrons carry magnets which re-

volve with them. These magnets act upon groups of fixed coils, set close to the polyhedrons, setting up alternating currents in

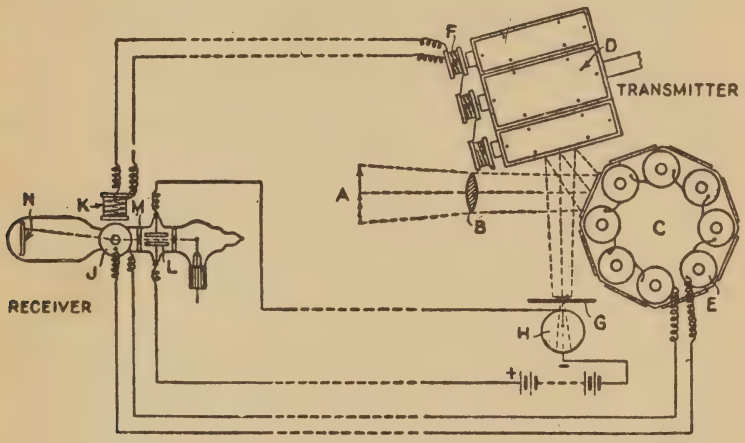


Fig. 13—Rosing's Cathode Ray Apparatus

them. Two alternating currents are generated in this way, one of them by one revolving polyhedron, and the other by the second polyhedron. Both currents are sent along separate pairs of wires to the receiver, where they are arranged to energize two electromagnets, K and J, one of which gives to the cathode ray vertical movement, while the other gives to it a much more rapid horizontal motion.

Transmission of Outlines

During the year 1925, C. Francis Jenkins, founder of the Society of Motion Picture Engineers, was broadcasting silhouette pictures from his studio in Washington, D. C. While John L. Baird in the same year successfully transmitted outlines of pictures from Selfridge's department store in Oxford Street, London.

Transmission of Shades and Shadows

True television, the transmission of shades and shadows, was

accomplished in 1926, when J. L. Baird gave a demonstration before some forty members of the Royal Institute in London. The London *Times* carried an account of this demonstration and we reprint part of the article here:

"Members of the Royal Institution and other visitors to a laboratory in an upper room in Frith Street, Soho, on Tuesday saw a demonstration of apparatus invented by Mr. J. L. Baird. . . .

"For the purpose of the demonstration the head of a ventriloquist's doll was manipulated as the image to be transmitted, though the human face was also reproduced. First on a receiver in the same room as the transmitter, and then on a portable receiver in another room, the visitors were shown recognizable reception of the movements of the dummy head and of a person speaking. The image as transmitted was faint and often blurred, but substantiated a claim that through the 'Televisor,' as Mr. Baird has named his apparatus, it is possible to transmit and reproduce instantly the details of movement, and such things as the play of expression on the face."

A later demonstration of Baird's apparatus was described in "Nature":

"A series of demonstrations was given by Mr. J. L. Baird, of an experimental apparatus of his own design for wireless 'television' (*i.e.*, the simultaneous reproduction at a distance of an image of a fixed or moving object). The inventor does not claim any great perfection for his results, but we have seen the production in the receiver of a recognizable, if rather blurred, image of simple forms, such as letters painted in white on a black card, held up before the transmitter. Mr. Baird has overcome many practical difficulties, but we are afraid that there are many more to be surmounted before ideal television is accomplished."

In the transmitting apparatus, the object, strongly illuminated, is placed opposite a revolving disc provided with a series of lenses, each a little nearer to the center than the last, which project a series of moving images upon a selenium or other photo-electric cell, each a little displaced laterally from the

last. This is the equivalent of passing the cell over the whole surface of the object in a succession of close parallel lines. The light thus reaching the photo-electric cell is rhythmically interrupted by a rapidly revolving slotted disc, and the result is that owing to the variations of resistance of the cell, undulations at an audio-frequency are produced in the current through it, whenever a bright part of the object is being dealt with. These are amplified and supplied to a simple wireless transmitter, which is caused to emit corresponding signals.

In the receiving section of Mr. Baird's television apparatus, the signals sent out from the transmitter are detected and amplified by very powerful valves, until they are strong enough to light up a neon tube when a signal is received, *i.e.*, when a bright part of the object is being dealt with by the transmitting apparatus. A disc, with lenses or holes corresponding to the lenses of the transmitting disc, is rotated synchronously with the transmitting disc, causing spots of light produced by the neon tube to appear upon a screen in positions corresponding to the part of the object being dealt with. With a sufficiently rapid rotation of the discs, a recognizable image of the subject is produced. A duplicate of the receiving apparatus is provided at the sending end with its disc mounted on the same shaft as the transmitting disc, to enable the necessary adjustments to be made. Synchronism between the sending and receiving discs is obtained by a little alternator with a frequency of about 300 geared to the revolving system, which causes signals to be sent out by another wireless transmitter at this frequency. These are received and amplified at the receiving station to an extent enabling a similar little alternator connected to the receiving discs to be synchronized with them.

In April 1927, the American Telephone and Telegraph Company gave a demonstration by sending half tone images between New York and Washington, D. C. While in 1928 John L. Baird succeeded in transmitting images from Coulsdon, England across the Atlantic to Hartsdale just outside New York City.

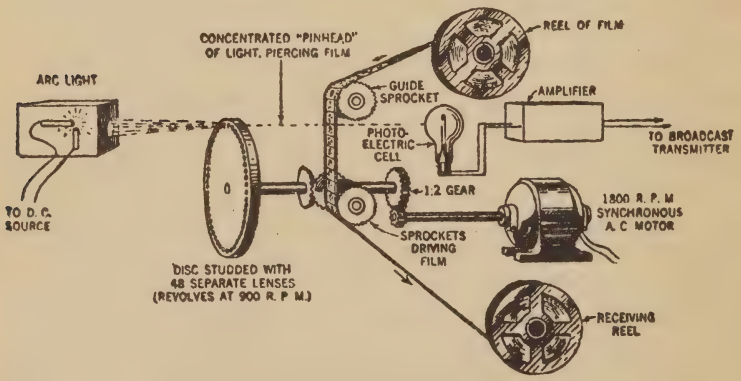
Radio Movies

On July 2nd, 1928 the Jenkins Laboratories, Washington, D. C., inaugurated the first regular schedule of broadcast radiomovies. Here is Mr. Jenkin's story pertaining to these broadcasts:

"These broadcasts were continued for an hour each Monday, Wednesday, and Friday, on 46.72 meters (6,420 kilocycles) for distant reception, and 186 meters for local receivers.

"Silhouettes only were transmitted initially, because picture stories in silhouette are easier for the beginner to pick up; and obviously the width of the picture-frequency band is very much less, and, therefore, the latitude is greater.

"Simple subjects were first broadcast, then more elaborate subjects, and still later picture stories. As with other broadcasting, an announcement preceded each feature, and each picture story finished with the word 'End.' A switch then



Jenkins Drum Type Scanner for Radio Movies

substituted the loud-speaker for the picture receiver again, ready for the next announcement.

"But it was soon discovered, in repeated broadcasts of radiomovies, that radio stories in silhouette were just as entertain-

ing as movie cartoons in the theater.

"It has been predicted that such broadcasts, combining pantomime fascination of motion pictures with the intriguing mystery of radio, will build up a demand for mechanisms never before equaled in the history of human entertainment.

"Nor has any invention ever had so much anticipating publicity—a publicity which antedated the actual completion of its successful attainment by fifty years.

"And this in spite of the fact that it is based on one of the simplest of the mysteries of our childhood, when mother drew parallel lines across a piece of paper, under which she had put a penny, and made a picture of the Indian appear. The explanation, of course, is that the humps on the penny varied the pressure of the pencil on the paper to build up a picture, though the lines were drawn straight.

"This is exactly the process employed in the reception of radiovision or television images. However, instead of a pencil the lines are drawn with a point of light, sweeping across the picture screen in successive parallel journeys, at the same time the intensity of the point of light is varied by the incoming radio current to make the picture.

"Each picture frame is thus covered every fifteenth of a second, and persistence of vision builds up the image directly on the eye, and we say we see the living person at the other end of the television wire or the radiovision channel.

"Because of the anticipating publicity referred to, and now that it is actually done, there probably exists a latent interest in visual radio which will unexpectedly burst into a torrential demand for receivers.

"Because such sets are not now available, it is expected that amateurs all over the country will be building their own motion picture receiving sets, just as they built their first crystal and headphone audio sets."

Television in Color

In July 1928, John L. Baird demonstrated television in color at a meeting of the British Association in Glasgow, his method

is described by Sidney A. Moseley and H. J. Barton Chapple in "Television Today and Tomorrow":

Taking advantage of the fact that red, green, and blue are the three primary colors from which every visual color can be built up by combinations, Mr. Baird made up a triple spiral disc, each set of perforations being covered with red, green, and blue light filters (see Fig. 18). Using this disc on the spot light system, it was thus possible to transmit, via the photo-electric cells, current pulses corresponding respectively to the red, green, and blue parts of the scene or subject televised. Naturally, a geometrically similar disc, covered with the same color filters, was employed at the receiving end, but it was essential to have a light source rich in red, green, and blue rays.

First of all a special glow discharge lamp containing a mixture of neon, helium, and mercury vapor was tried, but little

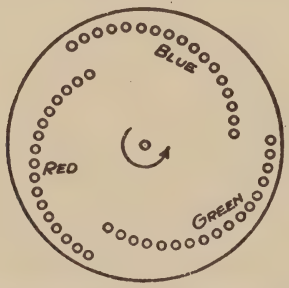


FIG. 18—Disc Covered with Red, Blue, and Green Filters is Required for Color Television

success attended these efforts, so it was decided to have two separate light sources.

Now the neon lamp itself is rich in the red rays, so an additional lamp, containing mercury and helium vapor, was constructed, the mercury vapor supplying the green light and also part of the blue, while the presence of the helium assisted in producing the blue light. Of course, the inclusion of two lamps at the receiver end complicated matters slightly, but this was overcome quite easily by using a commutator on the

driving motor shaft, so that only the neon lamp was illuminated when the red filter holes were revolving in front of the observer, the mercury and helium lamp taking its place as soon as the blue and green filter holes came into position.

To give the same number of complete pictures per second, whether red, green, or blue, the speed of the transmitter disc should be increased three times, but in actual practice this was found unnecessary, owing to parts being common in the three colored images.

Of course, it will be observed that the three individual signal images all pass along the same photo-electric channel, and thus only one wave length is required for transmission purposes. This is important, and will correct the impression that has got abroad that three separate communication channels are necessary.

Natural Color Television Using Color Filters

A system of color television using special photo-electric cells and color filters, was described by Dr. Ives of the Bell Telephone Laboratories in 1929:

One of the most significant features of this new achievement is that it does not require completely new apparatus. The same light sources, driving motors, scanning discs, synchronizing systems, and the same type of circuit and method of amplification are used as in the monochromatic system. The only new features are the type and arrangements of the photo-electric cells at the sending end, and the type and arrangements of the neon and argon lamps at the receiving end. The outstanding contributions that have made the present achievement possible are a new photo-electric cell, new gas cells for reproducing the image, and the equipment associated directly with them.

To render the correct tone of colored objects, it was necessary to obtain photo-electric cells which—like the modern orthochromatic or panchromatic plate—would be sensitive throughout the visible spectrum. This requirement has been satisfactorily met. Through the work of A. R. Olpin and G. R. Stilwell a new kind of photo-electric cell has been de-

veloped, which uses sodium in place of potassium. Its active surface is sensitized by a complicated process using sulphur vapor and oxygen instead of by a glow discharge of hydrogen as with the former type of cell.

The response of the new cell to color, instead of stopping in the blue-green region, continues all the way to the deep red. Because the former potassium cells were responsive only to the blue end of the spectrum, objects of a yellowish color appeared darker than they should have and the tone of the reproduced scene was not quite correct. This disadvantage applied particularly to persons of dark or tanned complexion. When the new cells are used in the original television apparatus and with yellow filters—similar to those used in photographing landscapes in order to make the blue sky appear properly dark—this defect is corrected and the images assume their correct values of light and shade no matter what the color of the object or the complexion of the sitter. It is the availability of the new photo-electric cells which makes color television possible by their use.

The development of color television has been greatly simplified by the fact that as far as the eye is concerned any color may be represented by the proper mixture of just three fundamental colors—red, green, and blue. This fact was utilized in the development of color photography, and all the research that had been done in that field was available as background for color television. A host of methods of combining the three basic colors to form the reproduced image was available but, insofar as the sending or scanning end is concerned, a method was developed which has no counterpart in color photography. The method of "beam scanning" has been employed.

Color Filters

To apply this method to color television, three sets of photo-electric cells are employed in place of the one set used before. Each of these sets is provided with color filters made up of sheets of colored gelatine. One set has filters of an orange-red color which make the cells see things as the hypothetical red

sensitive nerves of the retina see them; another set has yellow-green filters to give the green signal, and the third set has greenish-blue filters which perform a corresponding function for the blue constituent of vision. The scanning disc and the light source are the same as with the beam scanning arrangement used in monochromatic television. The only difference is in the photo-electric cells, and thanks to the tri-chromatic nature of color vision, it is only necessary to have three times the number of cells used previously to reproduce all colors. Three series of television signals, one for each set of cells, are generated instead of one and three channels are used for the transmission of the television signals.

The photo-electric cell container, or "cage," has been built in a somewhat different form from that used in our first demonstration. There three cells were used arranged in an inverted "U" in a plane in front of the object. In the new photo-cell cage twenty-four cells are employed, two with "blue" filters, eight with "green" filters, and fourteen with "red" filters. These numbers are so chosen with respect to the relative sensitiveness of the cells to different colors that the photo-electric signals are of about equal value for the three colors. The cells are placed in three banks, one bank in front of and above the position of the scanned object, one bank diagonally to the right, and another bank diagonally to the left, so that the cells receive light from both sides of the object and above. In placing the cells they are so distributed by color as to give no predominance in any direction to any color. In addition large sheets of rough pressed glass are set up some distance in front of the cell containers so that the light reflected from the object to the cells is well diffused.

The television signals produced in the color sensitive photo-electric cells through the color filters are no different electrically from those used in monochromatic television. Three sets of amplifiers are required, one for each color, and three communication channels in place of one, but the communication channels are exactly similar to those which were used with the same scanning disc before.

For color television the three images must be received in

their appropriate colors, and viewed simultaneously and in superposition. The first problem was to find light sources which, like the neon lamp previously used, would respond with the requisite fidelity to the high-frequency signals of television, and at the same time give red, green, and blue light. With such lamps available a decision would have to be made as to how the three colors could best be combined to form a single image.

Methods of Reception

Several methods of reception are possible. For displaying the transmitted image to a large audience a grid could be employed similar to that used for the earlier demonstration but it would consist of three parallel tubes instead of a single one.

Thus far the television images have been received in a manner similar essentially for monochromatic television. The surface of a disc similar to that used at the sending end is viewed, and the light from the receiving lamp is focussed on the pupil of the observer's eye by suitable lenses. To combine the light of the three lamps, they are placed at some distance behind the scanning disc and two semi-transparent mirrors are set up at right angles to each other but each at 45° to the line of sight. One lamp is then viewed directly through both mirrors and one lamp is seen by reflection from each.

The matter of suitable lamps to provide the red, green, and blue light has required a great deal of study. There is no difficulty about the red light because the neon glow lamp which has been used previously in television can be transformed into a suitable red light by interposing a red filter. For the sources of green and blue light nothing nearly so efficient as the neon lamp was available. The decision finally made was to use another one of the noble gases—argon—which has a very considerable number of emission lines in the blue and green region of the spectrum. Two argon lamps are employed, one with a blue filter to transmit the blue lines and one with a green filter transparent to the green lines of its spectrum.

These argon lamps unfortunately are not nearly so bright

as neon lamps and it was, therefore, necessary to use various expedients to increase their effective brilliancy. Special lamps to work at high current densities were constructed with long narrow and hollow cathodes so that streams of cold water could cool them. The cathode is viewed end-on. This greatly foreshortens the thin glowing layer of gas and thus increases its apparent brightness. Even so it is necessary to operate these lamps from a special "I" tube amplifier to obtain currents as high as 200 milliamperes.

Two Way Television

In 1929 the writer along with several other members of the Society of Motion Picture Engineers, was invited by the Bell Laboratories to witness a demonstration of two-way television between the Bell Laboratories in West Street and the offices on Broadway.

The system consists of two complete television transmitting and receiving sets, the apparatus being similar to the Bell Laboratory television sets of 1927.

The following is a detailed description of the apparatus employed and the manner of its operation, for this account we are indebted to Dr. Herbert E. Ives and the Bell Telephone Laboratories.

The physical arrangement of the two-way television system is shown by the pictorial sketch **Fig 22** and in the photographs **Fig 23** and **Fig 24** The terminal apparatus is largely concentrated into a booth,—the television booth—similar in many respects to the familiar telephone booth, and a pair of cabinets, which contain the scanning discs and light sources. As in the 1927 demonstration, scanning is performed by the beam method, the scanning beam being derived from an arc lamp whose light passes through a disc furnished with a spiral of holes and thence through a lens on the level of the eyes of the person being scanned. The light reflected from the person's face is picked up by a group of photoelectric cells for subsequent amplification and transmission to the distant point.

The signals received from the distant point are translated into an image by means of a neon glow lamp directly behind a second disc driven by a second motor placed below the first and inclined at a slight angle to it. The two discs, which are shown in the center cabinet of Fig 23, are slightly of different sizes; the upper one 21″ in diameter and the lower one 30″.

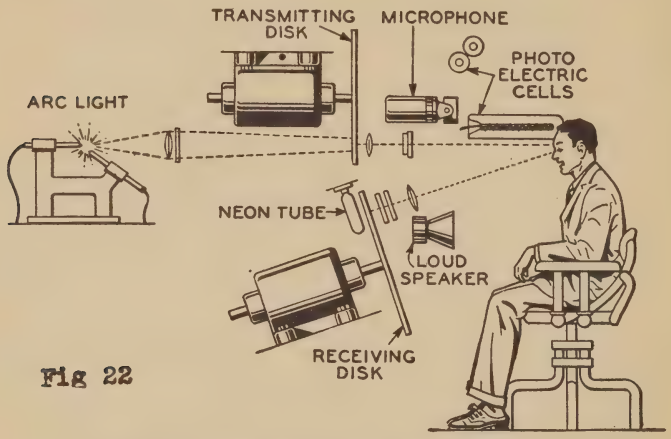


Fig 22

Schematic diagram of equipment used in demonstration of two-way television conducted by the Bell Telephone Laboratories.

They differ from the discs used in the earlier demonstration in that in place of the 50 spirally arranged holes formerly used, they carry 72 holes whereby the amount of image detail is doubled. While with the earlier "50 line" picture recognizable images of a face were obtainable, the aim in this new development was to reproduce the face so clearly that there would never be any doubt of recognizability, and so that individual traits and expressions would be unmistakably transmitted. This doubled number of image elements necessarily requires, for the same image repetition frequency (18 per second) twice the transmission band, or approximately 40,000 cycles as against 20,000 for the 1927 image.

The only part of the television apparatus visible to the user is the array of photoelectric cells which are in the television

booth behind plates of diffusing glass. In addition to the photoelectric cells and their immediately associated amplifiers, the booth contains a concealed microphone and loud speaker. By means of these, the voice is transmitted to the distant station and received therefrom without the interposition of any visible telephone instrument which could obscure the face.

From the standpoint of the user, the operation of the combined television and telephone system is reduced to great simplicity. He enters the booth, closes the door, seats himself in a revolving chair, swings around to face a frame through which the scanning beam reaches his face, and upon seeing the distant person, he talks in a natural tone of voice, and hears the image speak. Conversation is carried on as though across a table.

Optical Problems

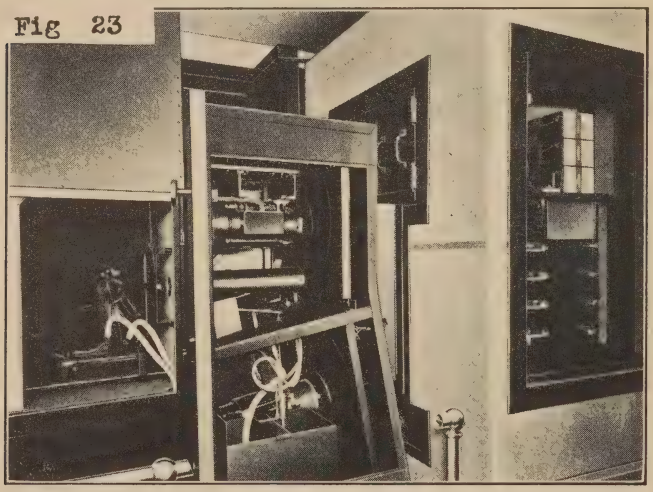
Some of the more special of the problems encountered in two-way television are primarily optical in character. The principal one is that of regulating the intensity of the scanning light and of the image which is viewed so that the eye is not annoyed by the scanning beam or the neon lamp image rendered difficult of observation. It has been necessary for the solution of this problem to reduce the visible intensity of the scanning beam considerably below the value formerly used and to considerably increase the brightness of the neon lamp.

The means adopted consist first, in the use of a scanning light of a color to which the eye is relatively insensitive but to which photoelectric cells can be made highly sensitive. For this purpose blue light has been used, obtained by interposing a blue filter in the path of the arc light beam, and potassium photoelectric cells specially sensitized to blue light and more sensitive than those previously used have been developed. The number of these cells and their area has also been increased over those used in the earlier television apparatus so that the necessary intensity of the scanning beam is decreased.

The second half of the problem, namely that of securing a maximum intensity of the neon lamp, has been attained by the development of water-cooled lamps capable of carrying a high

current. The net result of the use of the blue light for scanning, of more sensitive photoelectric cells, and of the high efficiency neon lamps is that the user of the apparatus is subjected only to a relatively mild blue light sweeping across his face, which he perceives merely as a blue spot of light lying above the incoming image. Fig 24 shows the interior of the television booth with the frame through which the observer sees the image of the distant person.

Fig 23



The three major units of the apparatus used in the two-way wire television demonstration. The terminals of the photoelectric pick-up system are in the unit at the right; the scanning discs for pick-up and reproduction at the center and the arc light for scanning are at the left.

A second optical problem is the arrangement of the photoelectric cells required in order to obtain proper virtual illumination of the observer's face. As we have previously pointed out the photoelectric cells act as virtual light sources and may be manipulated both as to their size and position like the lights used by a portrait photographer in illuminating the face. In the present case, it is desired to have the whole face illuminated and accordingly photoelectric cells are provided to either side and above. One practical difficulty which is encountered is

that eyeglasses, which often cause annoying reflections in photography are similarly operative here. For this reason, it is important that the photoelectric cells be placed as far to either side or above as possible. The banks of photoelectric cells shown in **Fig 24** are accordingly much farther removed from the axis of the booth than were the three cells used in the first demonstration. In the position which has been chosen for the cells, reflections from eyeglasses are not annoying unless the user turns his face considerably to one side or the other.

The number of cells has been so chosen as to secure a good balance of effective illumination from the three sides and it has been found desirable to partly cover the cells on one side in order to aid in the modelling of the face by the production of slight shadows in one direction.

In addition to the optical features which are visible to the person sitting in the booth, there are very necessary optical elements which have to do with the positioning of the outgoing and incoming images. A practical problem which is encountered when customers of various heights use the apparatus is that the scanning beam, if fixed in its position, would strike too high or too low upon many faces. In order to direct the beam up or down as is required, a variable angle prism, consisting of two prisms arranged to rotate in opposite directions, is interposed in the path of the scanning beam. This prism, which lies directly in front of the projection lens used with the upper disc, is shown in **Fig 25** at *P*. Its rotation is controlled by a knob with a numbered dial. The exact position is determined by the operator by reference to a monitoring image which will be described below.

Another optical element which serves two purposes, is a large convex lens lying between the receiving disc and the observing frame, shown at *L*, **Fig 25**. This lens is used to magnify the incoming image to such a size that the image structure is just on the verge of visibility, under which condition the face of the distant person appears as though he were approximately eight feet away. In addition to acting as a magnifier, this lens serves to position the incoming image to fit the height of the user.

Photo-electric Cells and Associated Circuits

The photo-electric cells used in this apparatus are similar in shape to those used in the first demonstration, but somewhat larger. Each cell is twenty inches long and four inches in diameter, giving it an area of approximately eighty square inches for collecting light. The anode is made in the form of a hollow glass rod wound with wire. This construction prevents the electrical oscillations that would otherwise result from me-

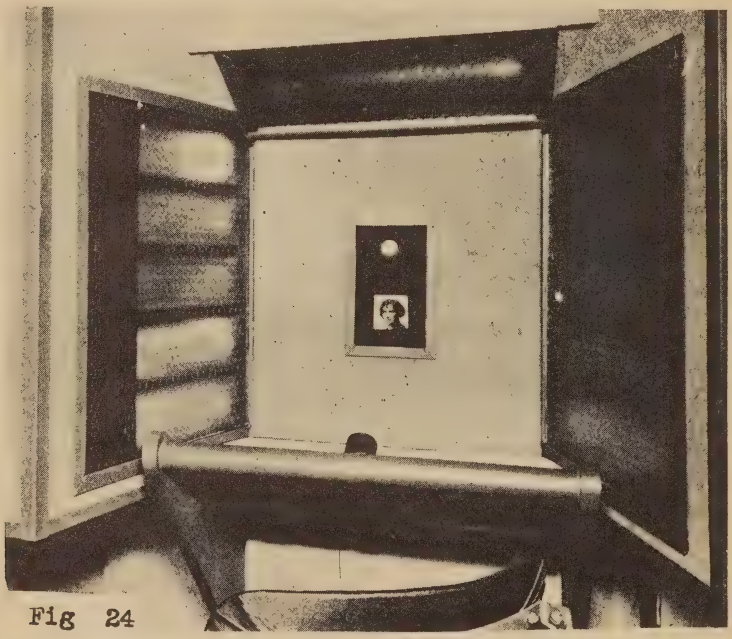


Fig 24

chanical vibrations of the anode. The sensitive cathode consists of a coating, covering the rear wall of the tube, of potassium sensitized with sulphur. This kind of cell is considerably more sensitive than the older type of potassium-hydride cell while still having most of the sensitiveness in the blue region of the spectrum.

To amplify the photo-electric current, the cells are filled with

argon at a low pressure. Photo-electrons passing from the sensitive film to the anode ionize the gas atoms along their paths and thus cause a greater flow of current. The ionization of the gas does not, however, instantaneously follow sudden variations of the true photo-electric emission from the sensitive film, that is, there is a time lag in the ionization of the gas and in the disappearance of ionization. This lag results in a relative loss and phase shift of the high frequency components of a television signal with respect to the low frequency components which become serious in the wider frequency range utilized in the 72 line image.

In the television booth, the twelve large cells mounted in the walls of the booth present an area of approximately seven square feet to collect light reflected from a subject. To secure the desired effective illumination, the cells are mounted in three groups, comprising a group of five cells in each of the two side walls of the booth and a group of two cells in the sloping front wall above the subject. The twelve cells are enclosed in a large sheet copper box, provided with doors to each group. The cells of each group are connected in parallel through the input resistance of a two stage resistance-capacity coupled amplifier similar to those previously used. This raises the level of the signal to such a point that the output of the three amplifiers may be carried through shielded leads and connected in parallel to a common amplifier.

The metal anodes and lead wires of the cells in parallel in any one group give an appreciable capacity to ground, which results in a further loss in amplitude and phase shift of the high frequency components of the signal.

Two-way Image Signal Amplifiers

The vacuum tube system used to amplify the photo-electric cell currents in two-way television is patterned closely after that used previously in one-way television, and the description here will be confined chiefly to novel features. These new features are necessary to take care of the doubled frequency band which results when the scanning is done with a 72-hole

disc rather than with a 50-hole one, and to provide sufficient power to operate the high intensity neon lamp which is essential to two-way television. Certain other new features have been introduced in order to simplify the apparatus and to reduce the maintenance required to keep it in good working condition.

The vacuum tubes which operate at low energy levels are the so-called "peanut" type, chosen because of their freedom from microphonic action and their low interelectrode capacities. Protection against mechanical and acoustical interference is secured by mounting these tubes in balsa wood cylinders which are loaded with lead rings and cushioned in sponge rubber. The tubes are electrically connected in cascade by means of resistance-capacity coupling, so that the whole amplifier system is stable over long periods of time and is also uniformly efficient over the required frequency band. Grid bias for the small tubes is supplied by the potential drop across a resistance in the filament circuit; the power requirements for the low level stages of the amplifier are filled by 6-volt filament batteries and 135-volt plate batteries, all located externally where they can be checked and replaced conveniently.

The amplifier system is divided into units of convenient size. Associated with each of the three banks of photo-electric cells is a two-stage unit known as the photo-electric cell amplifier; the combined output of these three units is carried to a four-stage unit known as the intermediate amplifier whose output is of sufficiently high level to be carried outside the copper cell cabinet to the three-stage transmitting power amplifier on the relay rack. A four-stage unit known as the receiving power amplifier is also on the rack, and serves to amplify the signal from the other station to a level which will yield an image of satisfactory contrast when it is translated into a light variation by means of the neon lamp. The final stage of this amplifier consists of two special 250-watt tubes in parallel. These large tubes are used because their plate impedance is of the same order of magnitude as the impedance of the neon lamp, and because they will supply the necessary direct current to the neon lamp without overheating.

It is interesting to observe that the signal voltage produced by the three banks of photo-electric cells has an effective value of about 50 microvolts across the 50,000 ohm input resistance; the transmitting amplifier delivers about 1 volt to the 125-ohm cable circuit, and the receiving amplifier delivers about 100 volts to the 1,000 ohm neon lamp circuit. The signal current through the neon lamp has an effective value about a thousand million times greater than that of the current variation in one of the photo-electric cells.

Transmission Circuits

Two special requirements for the two-way television transmission circuits are to be emphasized. The first, which has already been referred to, is the wide frequency transmission band, from 18 cycles to 40,000 cycles, which must have a high degree of uniformity of transmission efficiency and freedom from phase distortion. The second is the necessity for *two* circuits for the television images. This arises from the fact that the two parties to the conversation must both see and be seen at all times. There can be no interruption of one face by the other, comparable with the alternation of the rôle of speaker and listener in telephony which permits the use of a single circuit for ordinary speech communication.

The terminal stations of the two-way television system are connected by eight underground circuits, each consisting of 13,032 feet of No. 19 gauge and 390 feet of No. 22 gauge non-loaded cable. Two circuits are used for transmitting the image signals, two for the accompanying speech, one for the synchronizing current, two are used as order wires, and one is kept as a spare. All of the circuits have identical transmission characteristics, but equalization is necessary only on the two which carry the image signals.

Although the distance between the stations is small the requirements of the television system from the standpoint of freedom from noise and other interference require that considerable care be given to the selection of the cable circuits used. All terminal connections are made through balanced

repeating coils or transformers so that all of the circuits are balanced to ground. Also, in order to insure that the cross talk between the various channels be unnoticeable the terminal equipment is so adjusted that approximately the same amount of power is transmitted by each circuit.

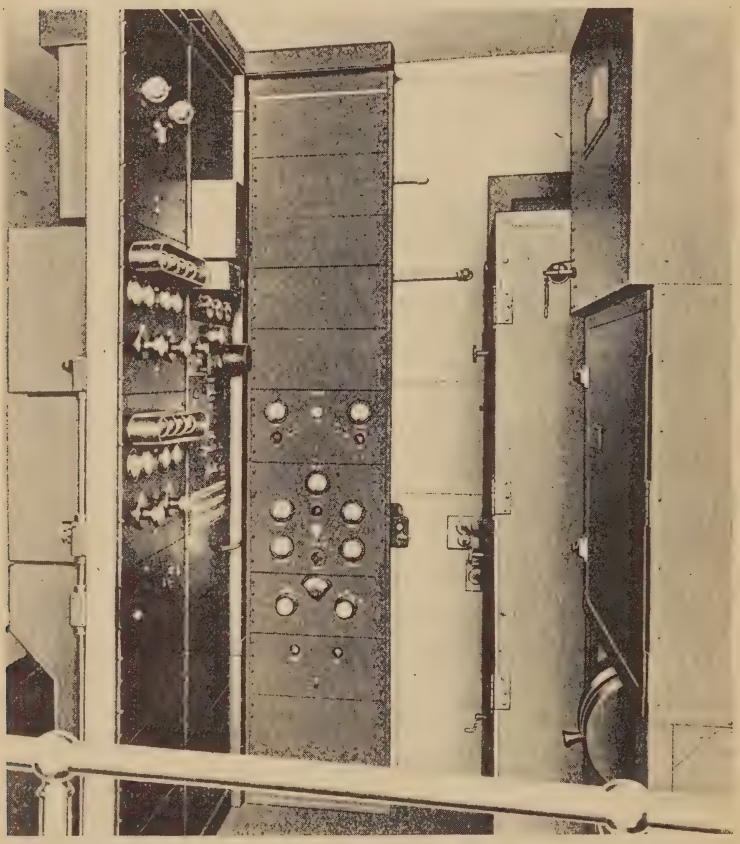


Fig 26 Control apparatus panels associated with one terminal of the television apparatus

Neon Lamps and Associated Circuits

After amplification, the received television signal is impressed on the grids of two power tubes in parallel to furnish current for a neon receiving lamp. The grid bias of the two power tubes is varied by the operator to control the D.C. plate current, which replaces the original D.C. signal component suppressed at the sending end. The quality of the reproduced image is determined by the operator's control over the relative levels of the incoming A.C. signal and the restored D.C. current.

The television current from the power tubes is translated back into light by a water-cooled neon lamp designed to operate on a large current. The structural details of the lamp are shown in **Fig 27**. Heavy metal bands attach the rectangular cathode to a hollow glass stem occupying the central portion of the tube. Water from a small circulating pump flows continuously through the glass stem and cools the cathode by thermal conduction through the metal bands. To reduce sputtering of the cathode and consequent blackening of the glass walls, the front surface of the cathode is coated with beryllium. This metal resists the disintegrating action of the glow discharge very satisfactorily and gives the lamp a prolonged life. Other metal surfaces in the tube are shielded from the discharge by mica plates; and the discharge passes from the frame-like anode to the front surface of the cathode, covering it with a brilliant layer of uniform cathode glow.

Pure neon in a plate type of lamp gives a very inferior reproduction of an image. The impedance of the lamp is relatively high and comprises both a resistance and a reactance which vary with frequency. The variation in the impedance causes a relative loss in the frequency components of the signal and also introduces spurious phase shifts. In addition, pure neon has an after-glow; the gas continues to glow for an appreciable time after current ceases to flow. This after-glow casts spurious bands of illumination out to one side of the brighter image details.

A small amount of hydrogen in the neon prevents such an afterglow; and at the same time improves the circuit char-

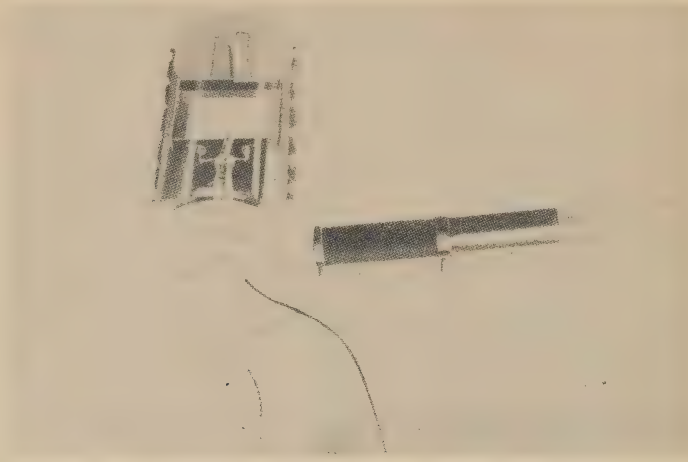


Fig 27—Water-cooled neon lamp

acteristics of the lamp. The total impedance of the lamp is lower, making it a less influential part of the lamp circuit; and the resistance and reactance vary in such a manner that the phase shift is more nearly proportional to frequency (a phase shift proportional to frequency causes no distortion in the reproduction of an image). Other active gasses may be used with the neon to improve the operation of a television lamp, but one or two per cent of hydrogen is most satisfactory.

Since hydrogen is absorbed by the electrodes in a glow discharge, it slowly disappears from the neon during operation of the lamp. For this reason the lamp is provided with a small side reservoir of hydrogen. The lamp and the reservoir carry porous plugs immersed in a pool of mercury; and a flexible rubber connection permits the two plugs to be brought into contact at will. Minute quantities of hydrogen may be introduced into the lamp by simply bringing the two plugs into contact for a short time.

Even with this improvement the circuit characteristics of a lamp are not ideal. With power tubes it is usually desirable to include a fixed resistance in series with the lamp to prevent semi-arcing conditions. Such a resistance also makes the lamp a less influential fraction of the total circuit impedance.

Optical Monitoring System

In order to insure that the incoming and outgoing images are properly positioned, no matter what the stature of the person sitting in the booth, and that the images shall be of proper quality, it is essential to have some means for the operator to observe and adjust these images. The optical monitoring system provided consists of an outgoing monitor and means for adjusting the scanning beam, and an incoming monitor and means for adjusting the position of the viewing lens to suit the height of the sitter.

The outgoing monitoring system is the same as that used in the one-way television apparatus. A small neon lamp (Fig. **28** , at bottom of top disc) is placed behind the sending disc but displaced several frames from the aperture through which the arc lamp beam passes. By continuing the spiral of holes part way around it is possible to see the complete image from the auxiliary neon lamp, to which the outgoing signals are also supplied. In order to see this monitoring lamp from the operator's position, a right-angle prism and a magnifying lens are placed in front of the disc and the image is observed through an opening in the side of the motor cabinet. The task of the operator is to direct the scanning beam up or down by means of the variable angle prism until the face of the person in the booth is centrally located. This adjustment is facilitated by a wire which passes across the image and is placed at the height at which the user's eyes should appear.

The height of the observer's eyes is an indication of the position which should be taken by the large magnifying lens *L*, and the operator, after having properly placed the scanning beam, reads the scale on the variable angle prism dial, and then sets the magnifying lens by turning its controlling knob to the

same number. When both adjustments are complete, the person in the booth will not only be properly scanned but will be in the best position to see the image.

In order to monitor the incoming image, an optical arrangement is adopted by means of which light from the water-cooled

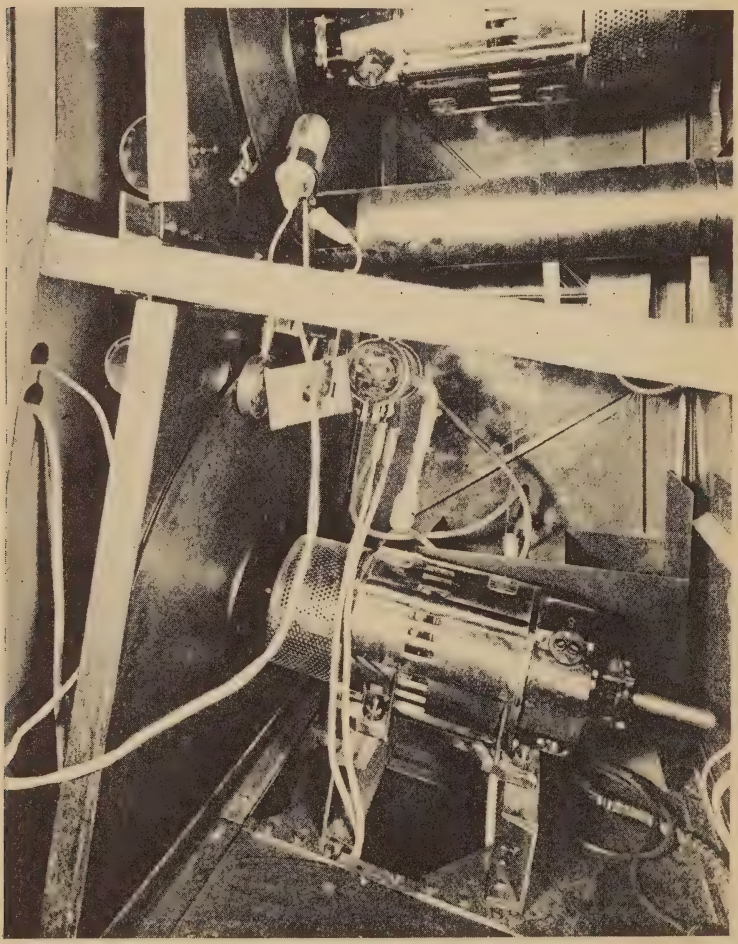
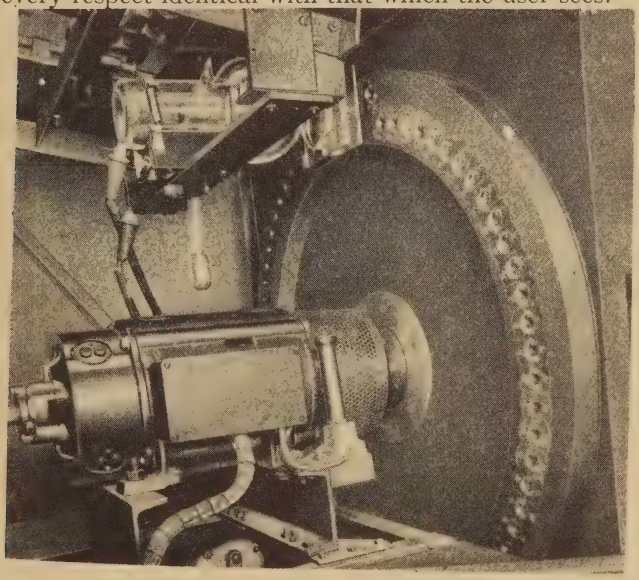


Fig 28 –Sending and receiving discs, with neon lamps and optical arrangements for image monitoring

neon lamp is taken off at the side and reflected through the disc and thence reflected again, as shown in **Fig 28** (top of bottom disc), through a second, lower, observing hole on the side of the motor cabinet. Because of the small area of the side view of the neon lamp, a lens system is inserted which focusses the image of the lamp at the place to be occupied by the pupil of the operator's eye. When the eye is properly placed, the whole of the lens area is seen filled with light and exhibits the incoming image.

In addition to the monitoring means just described, an additional view of the incoming image is provided by means of a 45° mirror which is carried on the back of a movable shutter which is shown at *S* in **Fig 25**. This shutter carries an illuminated sign on the side turned to the user with the inscription "Watch this space for television image." The shutter with its sign covers the image until the adjustments just described are made, when it is dropped out of sight. While it is in place, the operator is provided with an additional monitoring image reflected from the 45° mirror. This view is, of course, in every respect identical with that which the user sees.



PROGRESS SINCE 1939

The progress of field Television since 1939 up to the present time is paralleled by the advancement made by the RCA and National Broadcasting Company over this period, so a resume of the history of NBC prepared by R. E. Shelby and H. P. See for the RCA REVUE will be given here.

Field operations for NBC television broadcasting is divided into four rather distinct periods, determined principally by the characteristics and capabilities of the pickup equipment available during each period.

It is true that much progress was continuously being made at all stages in the development of this service on matters of technique and operating procedures, but it is, nevertheless, also true that the characteristics of the pickup equipment were the major factors in determining the scope of field television operation. The four periods referred to may be classified as follows in terms of the pickup equipment available in each:

1. Iconoscope Studio Type Equipment permanently mounted in large vehicle.
2. Orthicon Pickup Equipment permanently mounted in large vehicle.
3. Transportable Suitcase Type Pickup Equipment.
4. Equipment Employing the Image Orthicon.

The fourth period is the one which we are just entering and it gives promise of surpassing by far all previous records with regard to the wide variety of events which will become available for television broadcasting.

In addition to the pickup equipment employed in field operation, it is, of course, necessary to provide a suitable means for transmitting the television signal back to the main studios or to the broadcast transmitter. This may be done by either radio relay circuits or wire lines. Both means have been used successfully in the past and there is every indication that we will see the continued use of both means for at least some time to come. Progress made in microwave

radio frequency equipment for a variety of uses during the war will undoubtedly lead to substantially improved radio frequency links for this television relay application in the near future.

ICONOSCOPE STUDIO TYPE EQUIPMENT PERMANENTLY MOUNTED IN LARGE VEHICLE

Some indication of the rapid development that has taken place in television pickup equipment may be obtained by examining the facilities available for field operation at the beginning of the NBC television public service on April 30, 1939. A large van type of vehicle was necessary to house and transport the studio

Fig. 30

type equipment—cameras, camera and power cable, microphone cables, interconnection cables, and the large variety of accessories required to do a proper job on a field set-up. Despite the size of these vehicles (a second vehicle of about the same size housed the permanently mounted radio relay transmitter), they were relatively efficient and mobile. (See Fig. 30). Their size and weight did prevent their reaching marshy or sandy locations, and some areas where parking was at a premium were difficult to reach. They were, how-

ever, capable of moving normally in city traffic and on the open road. The great disadvantage from an operating standpoint lay in the fact that the equipment was, of necessity, permanently mounted in the vehicles. The cameras were equipped with 250 feet of camera cable and this accordingly was the radius of action from the vehicle housing the control equipment.

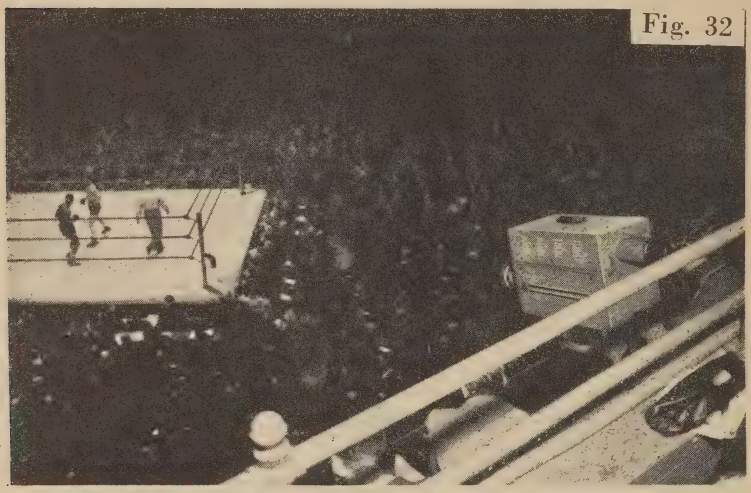


Fig. 32

—Orthicon Camera in Use in Madison Square Garden

The original equipment installed in this large vehicle employed an iconoscope camera and studio type rack-mounted amplifiers, control equipment and synchronizing signal generator. At the time this equipment was built, the iconoscope was (and in some respects still is) the most satisfactory type of direct television pickup tube available. With medium and high levels of illumination, it produced highly satisfactory pictures and for day-time out-door television operation where the incident illumination did not fall below several hundred foot candles, the results obtained were generally good. In addition to the fact that the pictures obtained under conditions of very low light levels were degraded by excessive amounts of "dark spot" signal,

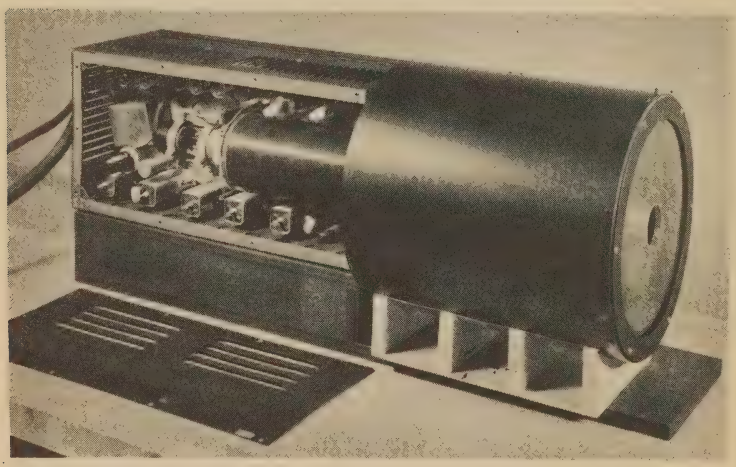
edge flare, and other defects, it was soon found that the iconoscope had additional limitations in field opera-

Figs. 33

Transportable Iconoscope Camera in Temporary Studio Set-up GOP Convention, Philadelphia, 1940.

tion which were not in its use in the studio. As regards the use of iconoscope cameras, studio operation has, in effect, a threefold advantage over field operation. In the studio, the lighting is under control of the operator and may be modified to suit the needs of the scene being televised; scenery, back-drops and drapes may be employed having light reflection characteristics suitable for the camera; and finally, in studio operation rehearsal will usually have given the operator a knowledge of the shading problem to be encountered as the program progresses. On the other hand, in field operation—especially outdoors—the lighting is generally not subject to any control, and may fluctuate over a wide range; the scene being televised in many instances may have an unfavorable background or direction of

the lighting may be unfavorable; and usually the event being televised is spontaneous and unrehearsed so that the operator has little warning of the changes to be encountered in shading. During this period of the NBC field television operation, the fact that peak field program hours occurred between the months of June and September was not because most field events suitable for television pickup occurred during those months, but rather because most of the *outdoor* events of this kind occurred at that time. The field program curve tapered off in November during the football season and took a sharp drop as the gridiron season ended. During



Camera Assembly with Reflective Optical System

the winter months, an occasional outdoor program was originated and a few indoor programs were attempted using added illumination for the benefit of the iconoscope camera. Many events which would have made good television programs could not be transmitted because of the amount of light required by the iconoscope camera.

Despite the limitations imposed by the equipment in use, several hundred interesting and timely television programs were presented originating at loca-

tions as far as 28 miles from the main studios. Although the iconoscope suffers from relatively low sensitivity in comparison with other types of pickup tubes, when an adequate light level is available, the overall quality of the picture obtained with an iconoscope camera is probably superior to that from any other type of pickup device so far used in the program service.

The outstanding program originated with this first field pickup equipment was the inauguration of the television public service on April 30, 1939, when the late President Roosevelt was televised during the opening ceremonies of the New York World's Fair. A program more typical of field operation with this equipment, however, was the pickups of tennis matches at the Westchester Country Club at Rye, New York, during the summer of 1939.

ORTHICON PICKUP EQUIPMENT

A major revision in the field pickup equipment was made during the month of September, 1939, when a new camera employing the orthicon type of pickup tube was substituted for one iconoscope camera in the mobile unit. For some time thereafter, the unit was operated with a combination of one orthicon camera and one iconoscope camera. The importance of this change in equipment lay in the relatively greater sensitivity of the orthicon tube. Although a direct comparison in sensitivity between the orthicon and the iconoscope is difficult because of their differing contrast characteristic, the orthicon has an effective sensitivity between 3 and 10 times that of the iconoscope for scenes of low incident illumination. In addition, it is essentially free from spurious signals, such as the "dark spot" in the iconoscope. With the orthicon camera, the scope of television field activity was immensely widened. Many events previously unavailable because of the lighting problem now could be satisfactorily televised. The second halves of football games played in the late Fall were now made entertaining as television program fare whereas with the iconoscope, particularly on overcast days, the pickup had been very unsatis-

factory. Even with the orthicon camera, in late November and early December, the light condition near the end of the games sometimes was such that the picture quality was seriously degraded. In some instances, the light level dropped so low that floodlights were turned on for the benefit of the players and spectators and under these conditions the orthicon gave very satisfactory results. Another important advantage of the orthicon, in comparison with the iconoscope, is the smaller mosaic size. The area of the mosaic of the orthicon is only approximately one-fourth that of the iconoscope, and this permits the use of substantially smaller lenses to obtain the same angle of view. This is a fairly important item in field operation where a large assortment of lenses must be provided to obtain various viewing angles depending upon the available camera location and the type of coverage contemplated.

Perhaps the most important class of programs made available for the first time by use of the orthicon camera was the large class of indoor sporting events such as boxing, wrestling, ice hockey, basketball, indoor track, etc. Nearly all of these events are presented under conditions of lighting which are satisfactory for the orthicon camera but too low for useable pictures with the iconoscope camera. The importance to television broadcasting of the availability of events of this kind can hardly be over-emphasized. They have formed an important part of the total television program service ever since the first orthicon camera was placed in service. Fig. 32 shows the orthicon camera in use for program pickups that are typical of the enlarged scope afforded television field operation by the use of this important development.

Although the orthicon has substantially greater sensitivity than the iconoscope and is essentially free from the spurious "dark spot" signal which plagues the iconoscope, it does have certain disadvantages compared to the earlier, less sensitive type of pickup tube. One of the principal disadvantages is its tendency to "charge up" when subjected to light intensity exceed-

ing a certain threshold value. This phenomenon is due to the inability of the low velocity electron scanning beam to completely discharge areas of the mosaic subjected to high light intensities exceeding a certain threshold value determined by the beam current. This weakness produces especially annoying effects on indoor pickups when photographers' flashbulbs are set off in the field of vision of the camera. This invariably occurs during climactic episodes of the event being televised and frequently portions of the most exciting action are lost to the view of the television audience before stable operating conditions can be re-established in the orthicon pickup tube. Trouble is also encountered in televising outdoor events in bright sunlight when a portion of the scene is in shadow and the rest in sunlight. Changes in the contest being televised which necessitate sudden and rapid panning of the camera from dark shadow to bright sunlight frequently lead to this "charging up" or blocking effect. It is minimized by operation of a special control that temporarily raises the value of the scanning beam current to an abnormally high value in order to dissipate the excessive charge on the mosaic.

The orthicon has a contrast characteristic (frequently referred to loosely as "gamma" characteristic), which is linear over its entire useful operating range. The iconoscope, on the other hand, possesses a contrast characteristic which exhibits a substantial amount of saturation in the higher light ranges and is, therefore, roughly equivalent to a "gamma" of less than unity. This contrast characteristic of the iconoscope complements rather well the corresponding characteristic of the kinescope tube used in most receivers so that the overall contrast characteristic of the system is generally satisfactory. When using the orthicon, however, it is necessary to provide in the video amplifier chains associated with the camera a controllable amount of saturation which will reduce the equavilent "gamma" characteristic to a value more suitable for the kinesope. Generally speaking, the combination of orthicon and its "gamma" correction circuit does not produce quite

as satisfactory an overall contrast characteristic as the iconoscope possesses, but it is hoped that future work will improve the "gamma" correction circuits. Despite the previously mentioned fact that the orthicon requires smaller size lenses than the iconoscope for a given angle of view, the sizes of lenses necessary to provide the desired range of camera angles are still substantial. The Type 1850 iconoscope requires a lens of 16" focal length, when the camera is located 70 feet from a boxing ring, to create images of the contestants which will be large enough when reproduced on the average receiver to provide optimum coverage of a prizefight. A lens of longer focal length and smaller viewing angle makes it difficult for the camera operator to follow the fast-moving contestants about

Televising the GOP Convention, Philadelphia, 1940. (Orthicon Camera in Foreground, Iconoscope Camera on Right.)

he ring and often results in one of the two fighters being out of the picture. The smaller mosaic in the orthicon tube allows the use of lenses which are approximately one-half the focal length of those used with the iconoscope camera for the same viewing angle. With the orthicon camera, boxing at Madison Square Garden is generally covered with a lens of 8" focal length, the distance from the camera to the ring being approximately 70 feet. Even with the reduction in lens size made possible by use of the orthicon pickup tube, it has not been considered feasible to attempt the use of lens turrets on these cameras.

TRANSPORTABLE SUITCASE TYPE PICKUP EQUIPMENT

The wider field of television activity permitted by the orthicon camera was still restricted by the limitation due to the location of equipment permanently mounted in a vehicle. The camera cables contained four flexible coaxial cables and thirty-two other electrical conductors and were 1½" in diameter. Storage and transportation difficulties, plus the need for compensating electrical networks to correct for pulse delay in very long cables were the factors which restricted the length of the camera cables to a practical value of approximately 250 feet. Shorter lengths of 50 feet each were carried for use where the longer lengths were not necessary. The 250 foot radius of activity of cameras was sufficient for most outside pickups when only two cameras were employed. Additional cameras, which would be those located at greater distances, could not readily be accommodated because of lack of space for additional control equipment in the vehicle. Field pickup service was restricted to coverage of events taking place below the fourth floors of buildings. Banquets, important meetings, interesting exhibits and panoramic scenes are among the potential programs which were unreachable with this equipment. The need for portable equipment which could be carried closed to the pickup scene became apparent early in field operations.

The development of the small iconoscope (Type 1848) transportable equipment which was contained

in eight boxes approximating the size of suitcases again greatly expanded the scope of the field service. The boxes, weighing approximately 65 lbs. each, were interconnected on the scene of action to form a complete operating chain of television pickup equipment. This equipment could be used for television pickup either in a vehicle in which it was transported or removed from the vehicle and carried to the upper floors of a building or to other locations inaccessible to the vehicle.

The availability of this transportable type of television pickup equipment again opened up new sources of television programs previously unavailable, and also increased the ease of operation in some cases where television pickups had previously been made with equipment permanently mounted in a vehicle. This type of equipment was used in the Rainbow Room atop the RCA Building in Radio City to televise the New Year's Eve festivities there in 1940. When the Republican National Convention of 1940 at Philadelphia, Pennsylvania, was televised and the signals transmitted via coaxial cable to New York for broadcasting, both the transportable type of pickup equipment and the equipment permanently mounted in the mobile unit truck were employed, thus providing a four-camera pickup. The four cameras were used to pick up both wide angle and close-up scenes inside the main Convention Hall, for studio type pickup in a small improvised interview studio and for pickups on the sidewolk in front of the Convention Hall .All sessions of the five-day convention were televised.

The photographs of Figs. 33 and 34 show scenes at the Philadelphia Convention pickup.

Transportable equipment employing orthicon cameras, became available shortly before the war and a two-camera system of this type has been used for the majority of all NBC field pickups since 1944. Fig. 35 shows the suitcase type equipment for the orthicon cameras situated on a movable table in a small control room at Madison Square Garden. This is the normal location for the control equipment during the televising of events in Madison Square Garden and its use here illustrates one of the advantages of the transportable

type of equipment. Prior to its availability, when televising events in Madison Square Garden, the large mobile unit vehicle was parked at the curb outside the Garden and camera cables and power and communication cables had to be strung in place for each program.

Although the transportable type of equipment has several distinct advantages, as already indicated, there are some offsetting disadvantages. In comparison with the older style of rack mounted equipment, the suitcase type of equipment is highly condensed and the components crowded rather closely together. This means that maintenance work and trouble-shooting are sometimes more difficult than in the rack mounted type of equipment. The large number of interconnecting cables with their sockets and plugs increases the chance for contact failure and delays occasioned by loss or damage. The smaller size of the monitoring kinescope and cathode-ray oscilloscopes is somewhat of a handicap in operations compared to the larger size screens used in the older equipment. Convenient accessibility of operating controls has had to be sacrificed somewhat in the interest of portability. In spite of these disadvantages, however, there can be no doubt that this type of equipment provides a substantial net gain in television field operation. It is interesting to note in passing that the extensive amount of work done during the war on highly compact military type of television pickup equipment which had to operate under very rigorous conditions will undoubtedly lead to significant improvements in future designs of transportable pickup equipment for the television broadcasting service.

IMAGE ORTHICON EQUIPMENT

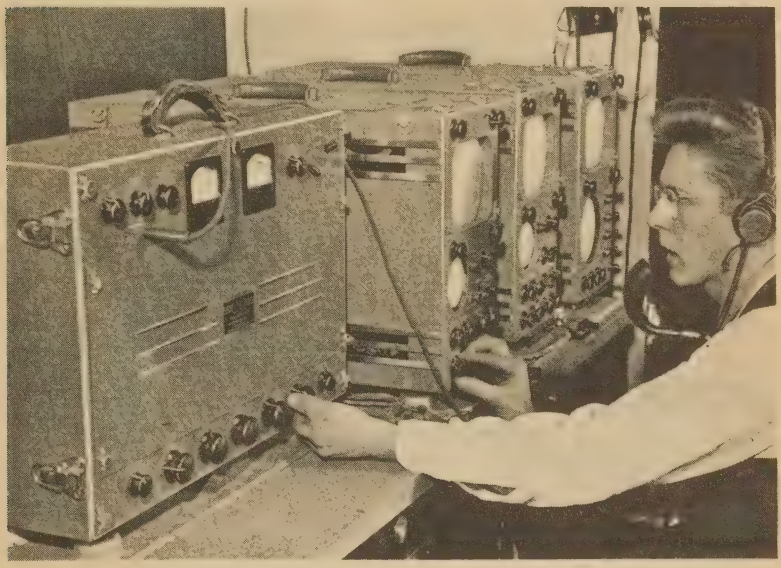
There has recently been announced a new type of television pickup tube known as the Image Orthicon which in comparison with any previously available pickup tube possesses rather startling characteristics, particularly as regards operation at extremely low levels of illumination. Development work on this tube had been started prior to the war but it received its greatest impetus as a part of the war-time research on mili-

tary television. It consists essentially of an orthicon scanning tube with an image electron amplifier section in front of the mosaic and a multiple stage electron multiplier at the output. It is still smaller in size than the Type 1840 orthicon tube, having a photocathode area approximately one-quarter that of the Type 1840 orthicon and one-sixteenth that of the larger iconoscopes. The sensitivity of the tube is such that it will produce satisfactory pictures at illumination levels lower by a factor of about 100 than those required for the iconoscope. In addition, it is much less subject to the "charging up" effect which is so troublesome in the case of the Type 1840 orthicon.

The importance of this new tube in television field pickups is self evident. It removes all practical barriers with respect to operation at low light levels. It seems safe to state that any event which has illumination adequate for direct viewing by an audience can be televised satisfactorily with the Image Orthicon camera.

The smaller length and diameter of the new tube plus its increased sensitivity and small photo-cathode area result in a camera substantially smaller than the standard orthicon field camera. The standard iconoscope and orthicon cameras in use today are considered too large and heavy for efficient handling in the field. The comparatively large mosaic areas of the iconoscope and orthicon tubes require optical systems of appreciable proportions. In contrast, the optical systems used with the Image Orthicon are about the same as those used on standard thirty-five millimeter motion picture cameras. Whether future camera models incorporate the twin lens optical viewfinder, the kinescope viewfinder or some other view-finding device, the reduction in the size of lens with the introduction of this tube makes practical the use of a lens turret. The sizes and weights of lenses included in the complement for a Type 1840 tube are generally considered to be approximately half those necessary for a Type 1850 iconoscope. The Image Orthicon reduces this by approximately one-half again for the same viewing

angles. The back of a lens turret in some cases in the past has imposed a limitation upon the latitude of operations and programming.



There are characteristics of the Image Orthicon which, at least for the present, partially offset some of its advantages. Its signal-to-noise ratio is not as good as that of the iconoscope under conditions of strong illumination, although at low levels of illumination it continues to produce satisfactory pictures far below the levels at which the signals from the orthicon and iconoscope are completely submerged in noise. The lower signal-to-noise ratio of the new tube is generally not noticeable except on scenes which include relatively large dark areas. Test-chart resolution in excess of 500 lines has been obtained with the Image Orthicon, but it has not yet quite equalled the performance of the better iconoscopes in this respect. Models of the tube produced for military use and early samples available for tests in television broadcasting possess rather high infra-red sensitivity. This necessitates the

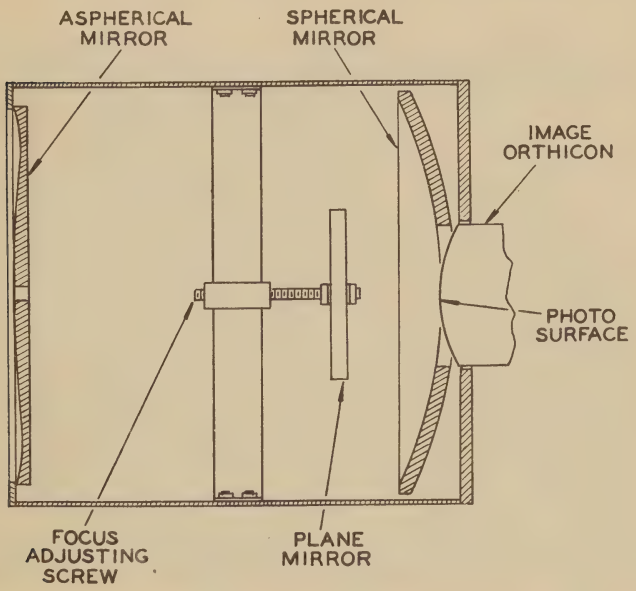
use of optical filters to attenuate the infra-red light when televising most outdoor scenes in daylight—particularly scenes which include appreciable amounts of living green foliage.

The Image Orthicon is more sensitive to ambient temperature than other types of pickup tubes. It does not give maximum performance until it has warmed up to approximately 100 degrees F., and when used outdoors in cold weather auxiliary heating units are sometimes needed. When the tube is too cold, its resolution may be impaired and retentivity of the electrical "image" on the target will be abnormal, producing excessive smearing in the reproduced picture whenever the camera is panned or when rapid motion occurs in the scene.

One important advantage which the Image Orthicon has over the Type 1840 orthicon is its ability to handle a very wide range of light values. If the various electrode potentials are properly set, a change in the scene from deep shadow to brilliant sunshine in outdoor pickups is readily accommodated without serious degradation in the transmitted picture and without the necessity for instantaneously coordinated readjustment of controls, as in the case of the Type 1840 orthicon. In one outdoor test, the Image Orthicon was adjusted for optimum performance with the iris on the pickup lens set for an opening of *f* 32. Without changing any other control, the iris setting was then changed to *f* 8, thus increasing the amount of light on the photocathode by a factor of 16. To the casual observer, at normal viewing distance, there was no appreciable change in the transmitted picture. In an indoor test at Madison Square Garden, it was found that a single suitably chosen setting of all controls would give acceptable results when the Image Orthicon camera was panned from the dimly-lighted outer fringes of the audience to the brilliantly-illuminated boxing ring at the center of the arena.

While it is true, as indicated above, that the Image Orthicon possesses great practical flexibility under varying conditions of illumination, it is also true that *peak*

performance will be obtained only when the settings of the iris and other controls are proper for the brightness of the scene being televised. Close inspection of the transmitted picture shows appreciable loss of information in the highlights if the light image on the photocathode is excessively bright, and signal-to-noise ratio will be lowered by operating the beam current at a value greatly above that required to discharge the tar-



get. In preparing for a television pickup, after the Image Orthicon has warmed up to normal operating temperature, the entire scene to be televised should be explored with the camera to determine, to the extent possible, the upper and lower limits of reflected light to be expected from the scene during the program. Settings of the iris, beam current, and other controls should be made in the light of this test, and if wide fluctuations in brightness are to be encountered, plans should be made for readjusting beam current and iris opening at proper times during the program.

Television broadcasting experience with the Image

Orthicon camera has included the following pickups:

1. *Herald-Tribune Forum, Grand Ballroom of Waldorf-Astoria Hotel.* Moderate illumination as normally used for audience.
2. *Navy League Dinner, Grand Ballroom of Waldorf-Astoria Hotel.* Moderate illumination as normally used for audience.
3. *Army-Navy Football Game.* The day was an unusually bright one for the season, and offered no test of sensitivity, but did afford a good comparison with orthicon cameras under conditions of high-level illumination. (See Fig. 36).
4. *Mayor-Elect O'Dwyer of New York City, from his campaign headquarters in the Commodore Hotel on Election Day.* Illumination provided by two 100 watt lamps in a frosted glass shade, and a 40 watt lamp for relieving shadow areas on faces.

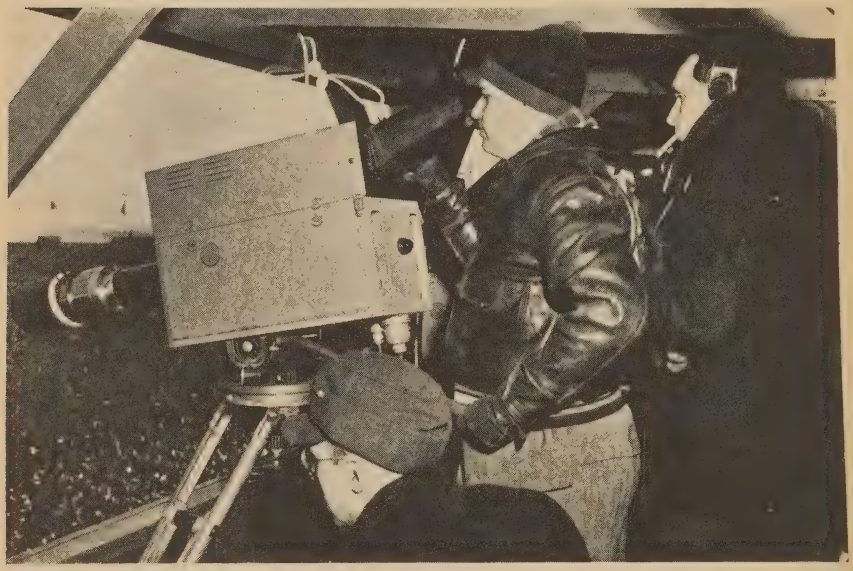


Image Orthicon Camera Televising Army-Navy Football Game Philadelphia Municipal Stadium, December first, 1945.

5. *New Year's Eve Celebration in Times Square, New York City.* Illumination as normally present in Times Square at night—from electric signs, street lamps, theatre marques, show windows, and automobile lights.
6. *Memorial Service at Lincoln Monument, Washington, D. C., on February 12, 1946.* A program originated jointly by stations WABD, WCBW, and WNBT and transmitted to New York over the coaxial cable of A. T. and T. to inaugurate television service over this cable.
7. *The Joe Louis, Billy Conn* fight for World's Heavyweight championship at New York Ball Park on June 19, 1946.

In addition to the foregoing on-the-air programs originated with the Image Orthicon camera, a number of successful test pickups have been made. These include the following:

1. *Baseball game at Polo Grounds, New York City.* The day was a bright one, and it was found that the minimum lens stop available—*f* 32—gave more than the optimum amount of light. Depth of focus was, naturally, no problem. A filter had to be used to reduce the infra-red light reflected from the grass of the playing field. Most observers felt that the Image Orthicon camera had a net advantage over the Type 1840 orthicon camera, which was set up for comparison.

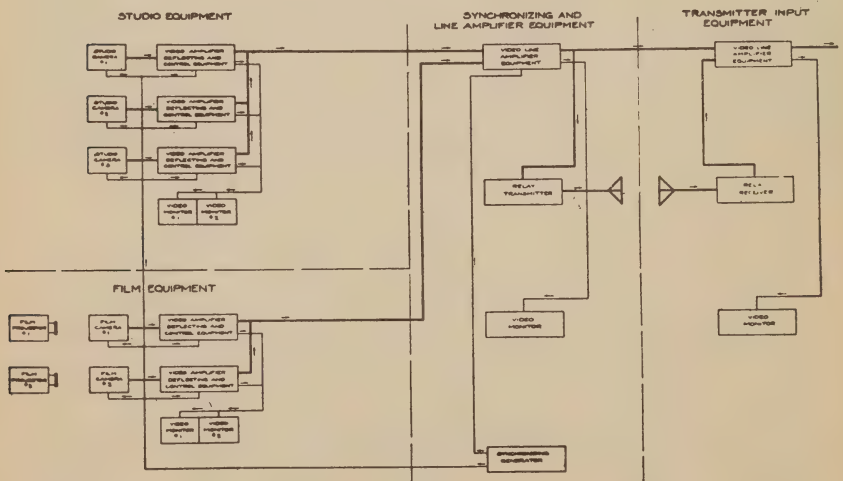
2. *Strollers on the Mall at night in Central Park, New York City.* The only illumination was that provided by the normal light fixtures in the park.

3. *Scenes from the Rodeo in Madison Square Garden, New York City.* The dark tan-bark on the floor, and the relatively low light level employed for many events to avoid blinding the contestants, had made this a relatively unsatisfactory program for orthicon cameras. The Image Orthicon camera was able to do an excellent job on all events.

4. *Television Pickup of Standard Sound Broadcast.* No special lighting of any kind was employed, and those in the studio did not even know that the test was being made.

5. *"Stunt" Pickups in the Studio.* Successful pickups were made using only the light of a pocket flashlight, or a single candle, or one match, and also in total darkness, using invisible infra-red illumination.

The importance of the Image Orthicon development to field television broadcasting is emphasized by statistics of operation which show that in the past more than one-half of the seven hundred odd field programs have originated indoors under artificial illumination—despite the fact that many potential indoor programs had to be passed up because cameras were not sensitive enough to give acceptable results with the illumination available. In the future, it is probable that the percentage of indoor programs will go even higher, now that there are virtually no technical limitations on the televising of such events. The economic advantages of the new camera are by no means insignificant, since the cost of providing special illumination for some events televised in the past has been a major item of expense. On the basis of experience to date, it seems safe to say that the Image Orthicon represents the greatest single advancement so far made in field television.



TELEVISION TERMINAL EQUIPMENT FOR RCA FIELD TEST SYSTEM

ELECTRONIC EMISSION

The word "electronics," which has become so popular lately, is derived from the word "electron." Electrons play such an important part in most modern devices, and their action is so little understood, that a description of their properties as well as the manner in which they can be controlled, should be beneficial.

Whether these electrons are really physical entities is open to conjecture. It is indisputable, however, that they have mass, that they can be weighed, and that they obey definite laws. It is their dimension and their shape that is vague, for, as a certain scientist aptly puts it, "No one can tell where an electron begins and where it ends." According to the more abstruse theories, electrons are nothing more than the crossing of lines of force. We will not, however, concern ourselves with the philosophical contemplation of the nature of electrons, but with the practical laws that govern them, and the simple electrons theory which explains all phenomena.

In order to fully understand the electronic theory, it is essential that a clear conception of the structure of matter be had. In elementary physics we are taught that matter consists of minute particles called *molecules*. These molecules are the smallest physically divisible parts of matter—physically divisible, because they can be further subdivided by other means into still smaller particles. For instance, by chemical means.

A molecule of water consists of three of these particles; two of hydrogen and one of oxygen. These smaller particles are called *atoms*. A molecule of water is, therefore, composed of three atoms. In the same manner, regardless of what matter is considered, it can always be subdivided to the ultimate atom. In certain elements, the atom is identical with the molecule.

The atom is still further divisible into two smaller kinds of particles, which are nothing but particles of positive and negative electricity. An atom is constructed as follows: A core called the nucleus, which is a positive particle of electricity called a *proton*, or an aggregation of protons and particles of negative electricity called electrons, is surrounded by one or more electrons which travel around it in orbits, at some definite speed.

Of particular interest at this time is that these protons and electrons are identical, no matter from what atom they may be derived, so that we must necessarily arrive at the conclusion that the properties of matter are simply dependent on the quantities of protons and electrons, as well as the manner in which they are grouped. It was said before that one or more electrons travel in orbits around the nucleus. It is with these electrons that we are concerned.

If one of these orbital electrons is removed from an atom, the remaining part of the atom becomes positively charged, which follows from the fact that in any atom, no matter how complex or simple, there are as many protons as there are electrons; so that the system as a whole is neutral (neither positive nor negative.)

An atom from which an electron is removed is called a positive *ion*. An electron is a negative charge of electricity, as was said before, so that when it is removed from an atom, the remaining structure is positively charged and the charge is of the same magnitude as the charge of the electron which has been removed. These orbital electrons can either be so strongly attracted by the nucleus that they can be removed only with great difficulty; or they can be so loosely

attracted that they can leave the atom readily and wander in the space between atoms.

Materials containing the first type of atoms are called *insulators;* those containing the second *conductors.* It follows from this statement, therefore, that a wire or any other form of conductor consists of an immense quantity of atoms with electrons that are free to move between the spaces of the atoms. Therefore when a potential is applied between the ends of such a conductor the electrons travel in the direction of the positive electrode of the applied potential (opposite charges attract each other while like charges repel each other), and a current is generated.

A current is simply a quantity of electrons passing a given point. When that same potential is applied to an insulator, the electrons which are more securely attached to the atoms may not move. If, however, the potential is increased, there will come a time when the attraction of the positive pole of the applied potential becomes greater than the attraction of the nucleus, so that the electrons are *forced* to move towards the positive pole. This is called the *rupturing of the insulator.*

Atoms within a piece of material oscillate in a haphazard fashion about a certain mean position, the motion being greater the higher the temperature. This agitation permits the dislodging of electrons much more readily. If the agitation is very violent—in other words, if the temperature is high enough—an insulator may become a good conductor.

This condition is aptly illustrated in glass. Glass at ordinary temperature is a good insulator; but at red heat it is a fairly good conductor. When the glass cools down, it again becomes a good insulator. This, however, is not the case with all insulators. Some insulators, as they have been disrupted, are permanently damaged and will never again serve as an insulator. To make this clear, it should be added that the disruption which is accompanied by intense heat at certain spots actually changes the *atomic structure* of the matter so that it is no longer the *same* material. Car-

bon derivatives are good illustrations of this condition. These carbon derivatives, as they become heated, become charred, and for the greatest part become plain carbon, which is a good conductor.

Let us now fix in our minds a picture of an atom: a nucleus, consisting of one proton, or an aggregation of electrons and protons, arranged in some definite manner; one or more electrons traveling at great speeds in orbits around this nucleus, and at a distance thousands of times greater than the diameter of the nucleus. Furthermore, these orbital electrons are more or less free to move away from the atom. To illustrate:

The hydrogen atom, which is the simplest of all atoms, consists of a nucleus of only one proton and no electrons; one electron traveling at a distance of approximately one hundred thousand times the diameter of the electron in some definite orbit around that proton. The proton has a mass about 2,000 times as great as the electron, so that the weight of this atom really is in the nucleus, which consists of one proton. The electron travels at a speed of approximately 70 miles per second around the nucleus.

A hydrogen atom, therefore, is simply one positive and one negative charge.

The distance between the individual atoms is millions of times greater than the diameter of the atom, so that here is where the peculiarity comes in. If we were to magnify the nucleus of a hydrogen atom to the size of the earth, an electron would travel around it at approximately the same distance as the sun is from the earth, and the next atom would be relatively somewhere in the Milky Way. A very peculiar condition, to say the least.

It appears, therefore, that there is very little of anything besides empty space in any piece of material. Matter is therefore a definite quantity of positive and negative distances, the charges bound to each other by certain forces, but for the greatest part it is just nothing. The same analogy holds pretty well for solid matter also, except that the distances between the atoms are not quite as great and the forces that hold the

atoms together are greater than the forces that hold gas atoms together.

Now we will consider the various methods in which electrons can be removed from atoms. The simplest has already been given. It is merely based on the elementary principle that like charges attract each other, while unlike charges repel each other. A positive potential, which is nothing else but a positive charge, attracts the electrons from the atoms. They move in the spaces between the atoms and proceed toward the positive charge. If that charge existed outside of the material, and if it was great enough, the electrons would leave the material altogether. Potentials necessary for this run into very high voltages; so high that they are impracticable.

It has been stated previously that temperature has an important influence on the ease with which electrons can be dislodged from atoms. If the material is heated, the potential necessary to remove electrons from it becomes smaller the greater the heat, and if high enough temperatures are employed, relatively small potentials will remove the electron.

At this stage another factor should be introduced. When the material is heated it is not only the positive potential that dislodges the electron, but the violent agitation of the atoms themselves causes some of the electrons to be thrown off. It is seen from this that emission can take place, (that is, if we understand by emission simply the *ejection* of electrons from matter), even when no potential exists outside of the material. Electrons so emitted have nowhere to go to, and because the material that they have just left has assumed a positive charge due to their absence, they are attracted back into it.

It is this principle of heating a piece of material to bring about emission that is employed in filaments and cathodes of thermionic vacuum tubes, and it is with this principle that we are mainly concerned.

In the interest of clarity, we will describe briefly the other methods of removing electrons. The next important one is the emission by light. If a piece of

material is struck by rays of light, electrons will leave the material. The quatities and the velocities by which they do this depends on the nature of the material as well as the nature of light. The mechanics of this type of emission is as follows:

Let us consider one ray of light striking the surface of a piece of material at a definite point. Let us assume that the material is struck at a point where there is an atom at that particular moment. Now, if the nature of the material is such that no appreciable reflection takes place and that it is opaque to light, something is bound to happen. It is a well-known fact that light is an electro-magnetic vibration. It therefore has energy. That energy is absorbed by that atom. The energy level of the atom is now higher than it was before, and the manner in which it evidences itself is by causing one or more electrons to travel at greater speed, probably at a speed high enough to permit the electron to leave the atom. This type of emission is used in photoelectric cells. We will not go into its finer points, as we really are not concerned with it. Let it suffice that we know that light can cause electrons to be emitted.

Now as to the third method of removing electrons. This method is easily understood. It is simply the removing of electrons by the impact of other electrons. An electron hits an atom with a certain speed and if the speed is great enough, the energy which was stored in that moving electron is imparted to the atom. The energy level of the atom is therefore increased. Again we come to the same phenomenon. If the energy level of atom is increased, something happens. If the energy increase is high enough, an electron leaves the atom.

The emission of electrons by electron impact is an important phenomenon in vacuum tubes. If it comes from electrodes within the tube, it is termed *secondary emission.* If it comes from the gas between the electrodes, it is termed *ionization.* A full description of all the laws governing secondary emission as well as ionization would be so extensive that it really deserves distinct consideration.

Now let us return to the emission of electrons by heat.

If a filament of any conducting material is heated sufficiently, the atoms of which this material is composed become violently agitated and for some reason permit electrons to fly off. If any particular atom happens to be at the surface of the material and if the energy level is sufficiently increased, an electron will leave the material entirely.

It is obvious that the ease wth which these electrons escape from the material through the surface is an important factor in electron emission. Why they shouldn't leave unhindered is all to evident, because within the material there is a force tending to hold them; without, there is nothing to attract them. The magnitude of the force within determines how easily they should escape.

This force is different in different materials. One filament will emit electrons more readily than another filament, at the same temperature. But any conductor will emit at some temperature. For practical purposes we are concerned with those materials which readily emit, and we are most concerned with those which emit most economically.

These emitters are divided into two great classes —simple emitters and compound emitters. Considering the simple emitters: It was stated before that any conducting material will emit electrons at some temperature, so that, based on this statement alone, any metallic wire is an emitter. This, however, is not true for the reason that some metals will melt or even boil before they reach the temperature at which they emit in sufficient quantities to be of *practical use.* Simple emitters are therefore restricted to those metals which have an extremely high melting point, such as tungsten, tantalum, molybdenum, etc. Carbon, which never melts, is obviously also a good simple emitter.

Now we come to the second great class, the compound emitters. These emitters are also divided into two classes—alloyed metals, such as thoriated and caes-

iated tungsten, and, secondly, metals which have been coated with a substance. The mechanics of compound emitters are a little bit more difficult to understand than those of simple emitters. We will consider one definite type—thoriated tungsten, for instance—so that the principles underlying the emission may be understood.

A piece of tungsten is alloyed in some manner with thorium. The exact manner in which this alloying is accomplished does not concern us. Suffice that we have a piece of tungsten filament in which we know there is thorium present. A potential is applied between the ends of this filament. The power dissipated in the filament is high enough to raise the temperature. Now what happens?

Simply this: the thorium, which melts and volatilizes at a relatively low temperature, rushes towards the surface and settles thereon. Now, if the temperature is not too high, practically no thorium will boil off. The thorium will be held to the tungsten in the form of an atomic layer (that is, only one atom deep) bya force which is called the *contact potential* between tungsten and thorium. Due to the fact that no contact potential can exist between thorium and thorium, the layer can never be deeper than one atom, because if a second atomic layer were piled upon the first atomic layer, nothing would hold it there and it would simply boil off. The contact potential, however, holds the first atomic layer most tenaciously, and temperatures far above the boiling point of thorium must be employed before it can be removed. At any rate, for our purpose we have now an alloyed filament which is entirely covered by an atomic layer of thorium.

Now let us consider this filament with a scientific eye. In other words, let us magnify it immensely. This is what we see.

The filament proper covered by atoms of thorium. The thorium atoms, which are at the extreme surface, each lose an electron by the first heat that is applied. They are, therefore, not any longer simple thorium atoms, but they are positive ions that are absorbed at that surface (*adsorption* is the clinging of particles

to a substance, and should not be confused with *absorption*, which is the permeating of those particles through a substance.)

Now let us consider a tungsten atom that finds itself below and between two thorium ions at a temperature sufficiently high to permit an electron to escape from it a short distance. In other words, this atom does not have very high velocity. As soon as an electron leaves the tungsten atom the thorium ions start working. Being positive, they attract the electrons with greater force than before, causing them to be projected farther from the tungsten emitter. And since these positives are spaced at various intervals, the force which they exert on that electron is not to themselves proper —or, more correctly, may not be to themselves proper —but may be a force in a direction perpendicular to the material.

That is emission.

If the thorium had not been present there, the electrons would never have left the surface. Electron emission from thoriated tungsten, therefore, *comes from the tungsten proper.* The thorium only aids the escape.

Now, the second class of emitters—those that are coated by some substance, usually an oxide. What exactly happens here nobody knows. However, theories which have never been disproven will be stated. The oxide by some means is reduced to the metal—for example, in the case of barium, to barium. This barium, by electrolysis (a process which allows electrons and ions to move between electrostatic poles), moves toward the surface of the metallic filament, which in most instances is nickel, or an alloy of nickel.

This barium, by forces similar to those which hold the thorium to the surface of tungsten, is held in a monatomic layer (one layer) at the surface of the nickel alloy. Emission then proceeds from the nickel alloy filament in the same manner as its does from tungsten. What further purpose the oxide serves is not clearly understood.

Thus far we have seen that after the electron has been emitted by the filament, no matter what the com-

position of the latter may be, it returns back into the filament for reasons given previously. If, however, a positive potential would exist in the vicinity of that filament, the electrons, after they have left the filament, would travel *toward* that potential.

A current between the filament and the electrode which has the positive potential is, therefore, set up. In this form electron emission has practical value.

Television studio equipment at Radio City

VACUUM TUBES

Electronic Emission

The basis of all vacuum tubes irrespective of their utility, whether of two, three or four elements, is the electronic emission from one of the elements within the tube. The vacuum tube as we know it today consists of a number of elements contained within a chamber, from which has been withdrawn all air and gases. This statement must be qualified somewhat insofar as the gases are concerned, because under certain conditions certain gases are permitted to remain within the chamber of certain types of rectifying tubes, such as the Tungar. However, at this time we are not specifically concerned with the evacuation of a tube but rather with its operation and utility. Consequently we will omit lengthy discussions of the effects of residual gases which have been deliberately placed within the tube, other than to mention where the presence of gases is detrimental to the satisfactory operation of the tube.

Referring again to electrons, we find them present in all metals and our reference to metals is based upon the fact that the electron emitting element within the vacuum tube is a metal. We made mention that the basic principle of operation of a vacuum tube is the electronic emission from a heated element, usually referred to as the cathode, sometimes as the filament. The electronic emission from an element is governed by two factors, the structure or consistency of the element and the degree of incandescence or temperature. The first is invariably very closely allied with the second since a vital item is sufficient electronic emission at minimum temperature. It is for this reason that certain substances are utilized as the source of electrons. Three kinds of filament material are employed in the everyday vacuum tube, namely tungsten, thoriated tungsten (a combination of tungsten and thorium) and platinum coated with certain oxides, such as Barium and Strontium.

Tungsten possesses certain properties which make it quite popular as a source of electrons. First, it emits electrons quite freely and second, it can be heated to a high temperature but the one disadvantage of the filament made of tungsten is that it must be heated to a high temperature, when compared with the required temperature of the other materials. However, the electronic emission from a tungsten filament at a certain temperature can be increased by the addition of a small amount of thorium to the tungsten before it is drawn to the correct diameter. When the filament is heated to the proper temperature, the thorium rises to the surface and constitutes what is practically a coating on the tungsten filament. It is this phenomenon which permits what is known as the "reactivation" of the thoriated tungsten filament, wherein after the first layer of thorium has been exhausted, the tungsten is heated to an abnormally high temperature to cause the thorium within the filament to rise to the surface, after which the filament is again operated at normal temperature.

Another classification of filaments is the oxide coated filament, previously mentioned, where a platinum wire or ribbon is coated with certain oxides, such as Strontium Oxide, Barium Oxide and Calcium Oxide. The salient property of these chemicals is the free emission of a great number of electrons at low heat or temperature. As a comparison of operating temperature between tungsten and a platinum filament coated with oxides, the former is operated at white heat, at a temperature between 2,200 and 2,400 degrees Absolute, while the latter is operated at a cherry red heat and much lower temperature.

Another distinct difference between the above two types of filaments is a structural change during operating life. The degree of volatilization of a filament increases with temperature and it is therefore easy to comprehend that a filament operated at white heat will volatilize much faster than a filament operated at a lower temperature. The action of this volatilization is to decrease the diameter of the filament and this is exactly what takes place with the ordinary tungsten filament. The thinner the filament due to evaporation, the greater its resistance and the problem of voltage or current control becomes

important. If the voltage is maintained constant during life, the current gradually decreases because the resistance of the filament increases. A decrease in current results in a decrease in temperature and electronic emission. On the other hand, if the current is maintained constant, there is danger of "burn out" since a reduction in the diameter of the filament means a reduction in its current carrying capacity.

The coated filament does not possess this property. First, the operating temperature is much lower and the volatilization is consequently less. Second, the operating life is governed by the life of the coating. Third, the heating current is carried by the core while what evaporates is the coating. Once the coating has been burned off the remainder of the structure is useless. Since the coating burns off before the core begins to diminish in diameter and mass, voltage or current regulation are equally satisfactory.

However, one significant fact is ever present with any form of structure which is used to supply electrons. While we are a little advanced, the time is propitious for the statement. Reference will be made later to some part of the vacuum tube referred to as the filament or the source of electrons. No matter what the form of structure, one should recognize that an increase in operating temperature of the source of electrons hastens premature demise of the complete tube. Operating at an excessive temperature reduces the normal period of obtaining sufficient electrons from the source. While it is possible to conserve this supply of electrons by operating at some temperature less than normal, operation at a higher temperature represented by either higher than normal voltage or higher than normal current will invariably ruin the tube in a very short time, and peculiar as it may seem, without any visible benefit because of abnormal operating voltage or current.

Types of Vacuum Tubes

There are in use today a large number of types of vacuum tubes, each designed to fulfill a certain specific function. However our discussion of vacuum tubes has not reached the stage

where we can discuss types according to function. Instead we shall merely mention general utility. Albeit the fact that the different types are quite numerous, the forms of utility are quite few, in fact, three in number. The first, is the use of the tube as a medium of amplifying or magnifying the intensity of the electrical equivalent of sound after it has been converted into electricity. This is the amplifier. The second, is the use of the vacuum tube to convert power available in A.C. form, that is A.C. voltage and current, into power in D.C. form, namely D.C. voltage and current. This process is known as rectification. The third, is the use of the vacuum tube as a medium of indicating the intensity of electrical impulses. The real phenomenon involved is once more one of rectification although the tube is not expressed as functioning in that manner. Such a tube is referred to as a level or volume indicator. Each shall be discussed in due time.

In order to comprehend the action of the vacuum tube, it is again necessary to refer to electric charges; their attracting and repelling action upon each other. An electron when emitted from an element is free to move in space. The fact that the space is a vacuum is of no consequence, as outlined earlier in this text. However, it is a negative charge and when free in space will be attracted to a positively charged body, if the latter is so located that its attracting force is sufficient and the electron is free to move towards it. What is true about one such free electron is true about myriad electrons. If sufficient electrons are thus passing from an electron emitting body, through space to a positively charged body, known as an anode because of its polarity, we have an electronic stream between the cathode and the anode. An electron in motion represents electric current and if some source of potential is employed to place the positive charge upon the anode, we have electric current in the circuit.

Such is the structure of the two element vacuum tube. Generally speaking, we can say that a two element vacuum tube consists of a chamber free of air and other gases, in which are located two elements; a source of electrons and a plate. If the source of electrons is a filament heated to incandescence

by electric current from a battery, that type of tube is usually known as a filament type of tube. The other element is a plate or flat disc mounted upon a stem and so located that the greatest area is directed towards the source of electrons. This plate may be located on either side of the filament or it may be one element of rectangular shape encircling the filament or it may be a circle of metal in the form of a tube with the filament within the hollow center. In American made tubes, suspension is in a vertical plane. A charge is placed upon this plate, by virtue of the application of a voltage across the filament-plate circuit, thus creating a difference of potential between the

FIG. 80

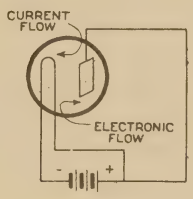


FIG. 81

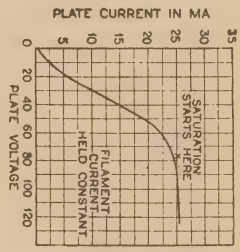


FIG. 82

cathode (filament) and the plate. The respective polarity of the plate and the cathode depends entirely upon the character of the potential.

The symbol for such a two element tube is shown in Fig. 80. It usually consists of an inverted V sign for the filament or source of electrons and a flat plate for the plate or anode. The ring encircling both elements is not standard.

If a circuit such as that shown in Fig. 81 is arranged, wherein a battery supplies voltage to the filament so that the current flow through the element heats it to the degree of incandescence required for satisfactory electronic emission, and another battery is connected as shown, between the filament and the plate, so that the plate is at a positive polarity with respect to the filament, the positive charge upon the plate will attract the electrons emitted from the filament. Hence a stream of elec-

trons will flow from the filament to the plate, as indicated by the single arrow. However, electric current flows from the positive to the negative, hence the current in the plate-filament circuit will assume the direction indicated by the double arrows.

If we consider in a case of this type that the electrons are current carriers, the intensity of the electronic stream will depend upon the magnitude of positive charge applied to the plate of the tube. This becomes evident immediately upon consideration of the fact that the number of negative electric charges which may be attracted to the plate depends entirely upon the intensity of the positive charge. If the electrons flowing between the filament and plate act as the carriers of the current due to the action of the battery, any variation in the electronic stream will cause a variation in the current due to the action of the battery which applies the charge to the plate.

The illustration in Fig. 81 shows two batteries. That which causes current flow in the filament or cathode so that it becomes an electron emitter, is known as the filament battery, designated as the "A" battery. That which supplies the potential to the plate of the tube or causes the application of the charge upon the plate, when it is in the form of a battery is usually referred to as the plate battery or "B" battery. If the source of this potential is not a battery, it is usually quoted as being the "source of B potential." The same is applicable in the case of the filament. This source of voltage is known as the "source of A potential."

An analysis of the circuit structure illustrated in Fig. 81 shows that the complete circuit consists of two separate circuits interconnected. One of these is the filament circuit, consisting of the source of electrons and the source of its operating potential. The other circuit consists of the plate (P), and the source of B voltage. These two however do not make a complete circuit. In order that current from the B battery finds its way back to the negative side of the B battery, it must flow through the filament, which means that one side of the B battery must connect to the filament circuit. When a positive charge is applied to the plate from a battery, the

negative (—) lead of the B battery connects to the filament and the positive side (+) connects to the plate. The complete circuit is therefore the plate-filament circuit, but it is usually referred to as the plate circuit.

The current flowing in the filament to heat it to incandescence, is known as the filament current and the current flowing in the plate circuit, when a complete path is provided via the stream of electrons between the filament and the plate is known as the plate current.

It is simple to appreciate that the electronic stream constitutes a path for the plate current. So much so that in many instances, the electronic emission is classed as the plate current. If this link, the electronic stream is removed, the circuit between F and P, the filament and the plate is open, hence current, due to the action of the B battery cannot flow. Such a condition may be brought about in two ways. First, no emission of electrons from the filament and second, by the application of a charge upon the plate of such polarity that the plate will not attract the electrons; which is the same as if we said that the polarity of the plate is negative. This point is quite significant since it governs the utility and application of the vacuum tube. If for some reason the polarity of the plate is charged from positive (+) to negative (—), current will not flow in the plate circuit during that period when the plate is negative with respect to the filament and the electrons. The reason for this is that the circuit is open because the link (the electronic stream) is missing. The filament however has nothing to do with this condition, because while in the incandescent state it is emitting electrons, but they congregate around the filament, some going back to the filament, but none passing to the plate. If this be true then the tube is a unilateral conductor, that is, conducting in only one direction, when the plate is positive with respect to the filament.

Thus we have a nucleus for what is to follow. We are familiar with the general structure of a two element filament type of vacuum tube and know that the filament supplies the electrons and that the plate under certain conditions of polarity with respect to the filament attracts these electrons.

Voltage Limitations

Since the electronic emission from a filament, (the number of electrons emitted in a certain period of time) is governed by the temperature, it stands to reason that at any one value of temperature, the filament emits a maximum number of electrons per period of time, for that degree of incandescence. If the temperature is increased, this number increases with a specific limit, governed by the structure of the filament. If the temperature decreases, the number decreases, but at any one constant value of temperature, the number of electrons emitted with respect to time is definitely limited to a certain maximum. However, the number of electrons of this maximum total, which actually reach the plate are governed by another factor, the attracting power of the plate, in other words the voltage applied to the plate or the potential difference between the two bodies. If you recall, potential difference in a measure of the tendency of charges to move from one body to another body or from one point to another point. From this we learn two significant facts applicable to everyday practice. The first is that electronic emission is definitely limited, since an increase in filament temperature above the tube manufacturer's rating which in everyday use is interpreted in the form of filament potential or current would result in irreparable damage to the filament. The second is that the plate voltage applicable to a certain tube is likewise definitely limited, since, when at a certain value of plate voltage all of the electrons emitted by the filament reach the plate, increase in plate voltage will not result in any further increase of plate current. When the maximum value of plate current has been reached because the plate cannot attract more electrons, plate current saturation is said to have been reached. An idea of such plate current saturation is shown in Fig. 82. This curve shows the relation between plate current and plate voltage, assuming that the temperature of the filament (filament potential and current) are held constant at one value, for a two element or two electrode filament type of vacuum tube.

RECTIFYING TUBES

Rectifying tubes find application as a means of converting power available as A.C. into power in the form of D.C. The process of rectifying provides a means of employing the regular 110 volt A.C. lighting and power mains as the original source of operating potential, thus obviating the need for the use of a bank of batteries. Rectifying also provides a very convenient means of developing power necessary for the "charging" of batteries, such as the storage cells mentioned earlier in the text.

The regular vacuum tube requires for its operating potential, a steady and constant voltage. Batteries supply this voltage. So does revolving machinery of the type illustrated in connection with the generation of D.C. It is necessary that some system be employed which will enable the utilization of the power mains as a source of D.C. voltage and current.

Upon the surface, rectification appears to be a very complex subject. While it is true that the finer details of design are intricate, sufficient rudimentary details are available to afford very satisfactory comprehension of the action of the vacuum tube as a rectifier.

We have observed that the tube possesses the property of unilateral conductivity. If we arrange a circuit such as that shown in Fig. 83, wherein two sets of B batteries are employed and the polarity of the voltage applied to the plate may be either positive (+) or negative (—), according to the position of the switch S, we find that when the switch is set to the + position, current is indicated upon the current indicating device located in the plate circuit and designated as MA, and when the switch is set to the — position, the current in the plate circuit is zero. Neglecting the B batteries in Fig. 83, we can arrange a circuit such as that shown in Fig. 84 where pro-

vision is made for the application of A.C. across the plate-filament circuit. No matter what the source of A.C. potential, one terminal connects to the filament circuit and the other to the plate. If some such source of voltage is connected across the two terminals shown, the circuit is identical to that shown in Fig. 83 except that the batteries have been replaced with A.C.

Mention was made in the chapter devoted to transformers, that this device will supply voltage when some other voltage is fed into the primary winding. Hence if we arrange a transformer with the input voltage supplied by the 110 volt A.C. power system and the output voltage is employed as the plate potential for the tubes we have a circuit such as that illustrated

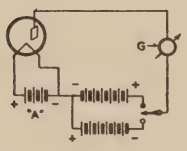


FIG. 83

FIG. 84

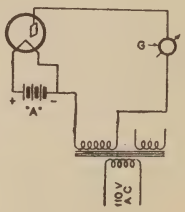


FIG. 85

in Fig. 85. By employing more turns in the secondary winding than in the primary winding of the power transformer Tr, the voltage applied to the plate is greater than the input voltage to the transformer.

The voltage now being applied to the plate of the tube is obtained from the secondary of the power transformer. In order that a complete circuit be available, one terminal of the secondary winding connects to the filament and the other connects to the plate through the current indicating device. A similar connection is possible when the current indicating device MA is not in the circuit. The voltage out of the transformer is A.C., hence the voltage applied across the plate-filament circuit is of A.C. character. Since the function of the A battery is to cause current flow through the filament in order to heat it to incandescence and cause the omission of electrons, it is

not essential that the source of voltage for the filament be a battery. It is possible to employ A.C. since this form of current will also heat the filament to the correct temperature.

We stated when discussing transformers that it is possible to employ a transformer with more than one output winding, each being individual and supplied with energy by virtue of the flux produced by the input current in the primary. Thus it is possible to employ a single transformer, with two output windings, one for the filament and the other for the plate, and one input winding for connection to the power mains. The voltage required for the tube filament is less than that required for the plate, hence the turn ratio between the primary and the filament winding of the transformer is such that the output voltage of this winding is less than that supplied to the primary, hence this ratio is "down." The ratio between the plate winding and the primary is "up," because the voltage fed to the plate of the tube in this case is more than the input to the primary. The revamped circuit appears as shown in Fig. 86. This is a typical rectifying circuit for reasons which shall now be stated.

The voltage from the filament winding, causes a sine wave of current in the filament of the tube. If the reader recalls the wave form of A.C. shown earlier in the text he will realize that the current fluctuates between zero and maximum at a certain rate, that is with a certain periodicity or a certain number of times a second. One would then imagine that the filament would heat and cool in accordance with the magnitude of current in the circuit. Such is not the case. The reason is founded upon the substance employed for the filament. Its structure is such that it retains the heat for a period in excess of the time between the moments when the current is maximum and when the current is zero. The direction of current as has been stated is of no consequence. This lag in the thermal activity of the filament enables the application of A.C. to the filament, with practically constant filament temperature, so that the emission of electrons does not undergo a change in accordance with the rise and fall of the current through the filament.

The action in the plate circuit is somewhat different. The filament is emitting electrons. The number of electrons which reach the plate, depends upon the charge applied to the plate (the polarity in this instance) and the magnitude of whatever charge is upon the plate. Mention was made in connection with the generation of A.C. that the voltage shown above the zero line is classed as positive and the voltage shown below the zero line is classed as being negative. Under such conditions, the voltage applied to the plate or the charge applied to the plate of the tube is alternately positive and negative. A sine wave of voltage such as that applied across the plate-filament circuit of the tube is shown in Fig. 87, and indicated by the solid lines. We know that opposite charges attract and that like charges repel. No matter what the magnitude of the like charges they will repel each other and no matter

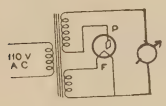


FIG. 86

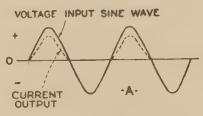


FIG. 87

FIG. 88

what the magnitude of the unlike charges they attract and the attracting force increases with the magnitude of the positive charge. If we now follow the action of the voltage applied to the plate of the tube we would find that current flow is indicated upon the matter during the moments when the voltage upon the plate of the tube is positive. We further find that the current indicated in the circuit increases as the magnitude of the positive voltage increases, so that during the positive half of the A.C. cycle, we find current in the form shown by the dotted line. When the voltage becomes zero, the current in the circuit becomes zero. When the negative half of the cycle is applied, the current in the circuit as indicated upon the meter remains zero, because the electrons emitted from the filament are repelled by the like negative charge upon the plate, hence during the complete negative alternation, current does not flow in the plate circuit. As the applied voltage again becomes positive,

we find a gradual increase in current in the plate circuit, coinciding with the changed intensity of the applied voltage. The aforementioned action during the negative alternation is again repeated and the process moves as outlined "ad infinitum."

The cumulative effect of this action is to produce in the plate circuit when A.C. is applied to the plate a series of pulses which are of D.C. nature, that is, always in the same direction, as shown in Fig. 88. Current during the positive half of the cycle and no current during the negative half of the cycle. In effect the negative half of the input voltage is cut off and we have converted A.C. into pulsating D.C. through a process known as rectification.

Investigation of the pulsating D.C. wave shows that the rectifying system is only active during one half of the complete cycle, hence the system is known as a half wave rectifier. Fur-

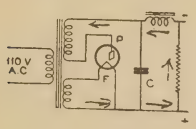


FIG. 89

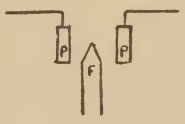


FIG. 90

FIG. 91

ther a symbol such as that previously quoted as being a two element tube is also a half wave rectifier. Such half wave rectifying tubes are those bearing the designation 281, 381 and others ending with the numerals —81. In addition three element tubes are also employed as two element tubes for rectification purposes by joining two of the elements within the tube.

It was stated that rectification allows the conversion of power available in the form of A.C. into power available in the form of D.C. The circuit shown in Fig. 86 is not the conventional rectifier system. The usual arrangement employed is that shown in Fig. 91. Let us analyze the direction of current flow and the current in the plate circuit of the tube. In this case, we have inserted a resistance R, so that current in the plate circuit must flow though this resistance. The plate winding is considered as replacing the B battery shown in Fig. 83, when

the plate is positive, the electronic stream is present between the filament and the plate, and plate current flows from the plate to the filament in the direction indicated by the arrow. The path of this current out of the rectifier circuit is from the filament as shown, so that the filament is positive with respect to the other end of the plate winding. Current flows through the resistance as a pulsating current, in the direction shown, so that one end of the resistance is positive with respect to the other. During the moments when the pulsating current is flowing through the resistance, a voltage is naturally developed across the resistance, which because of the uni-direction of the current is of D.C. character but pulsating instead of steady. While this form of voltage is not employed in a regular rectifier system used as a source of D.C. it nevertheless illustrates how we convert A.C. into D.C.

Full Wave Rectifier

It is possible by proper connection and utility of apparatus to employ the filament type of rectifier tube to function upon both halves of the input A.C. cycle. In this case it is necessary to employ two such half wave rectifiers in the form of two separate tubes or to arrange two such two element tubes within one chamber, which would then house two filaments and two plates or anodes. The utility of two such tubes is such that the plates of the individual tubes are actuated alternately. One plate or one tube functions upon one half of the cycle and the other tube or plate functions upon the other half of the cycle. The filaments of both tubes or rectifiers are of course incandescent at all times. The action of rectification is accomplished, by making one half of the input A.C. cycle positive for one plate and negative for the other. Then the alternating which is negative for rectifier number 1, becomes positive for rectifier number 2. Such full wave filament type rectifier tubes are illustrated as shown in Fig. 90 and 91. The symbol used to designate the filament indicates that the tube is of the filament type. When a circle encloses all the elements it means that two half wave rectifiers are in one chamber or that the two

plates or anodes are in one chamber. In other words the tube is single, yet houses the elements of a full wave rectifier tube.

The term "full wave" is applied because the entire cycle of A.C. is rectified. The wiring diagram of such a system is shown in Fig. 92. In some respects this circuit differs from the half wave rectifier, but in many other respects it is merely two half wave rectifiers interconnected. The two filaments are connected in parallel because they are operated at the same potential and are, in the operation of the rectifiers common. Since each rectifier is to operate upon one half of the cycle, the voltage applied to each rectifier must be the same, hence the plate voltage is secured from a center tap winding, which is the equivalent of two separate windings with a common terminal.

Suppose that we picture a cycle of A.C. applied to the rectifier system, as shown in Fig. 93. During the positive alternation plate 1 is active. We therefore have current flow through the resistance in the direction of the single line arrow and we have current as shown by the dotted line in Fig. 93. During the lower alternation, plate two is active and we have current flow through the resistance as shown by the double line arrows. It is evident that current flow through the resistance is always in the same direction. However, the pulsating current is now somewhat different than before. We do not have the lapse, or no current during the lower alternation as previously illustrated in Fig. 87. The pulsating current now varies in the manner shown in Fig. 94, and full wave rectification has been accomplished. The additional apparatus employed to enable utilization of the pulsating D.C. output of a rectifier shall be dealt with later when the subject of power supply devices are discussed.

Tungar Bulb

The current output of the filament type rectiners considered thus far depends entirely upon the function of the filament as the source of electrons. Such an arrangement is quite satis-

factory when the value of the output current is not very great. However, certain requirements necessitate a system where the current in the plate circuit, or the output is quite high, between 1 and 15 or 20 amperes. The number of electrons required to be the equivalent of such high values of current are not available from the filament. Such high values of current are encountered in units employed to charge storage batteries and to eliminate batteries as the source of filament voltage in amplifying circuits where A.C. cannot be applied to the filament because it interferes with reproduction of speech and music. In order to supply the required amount of current carried within the tube, the filament is not employed as the sole source

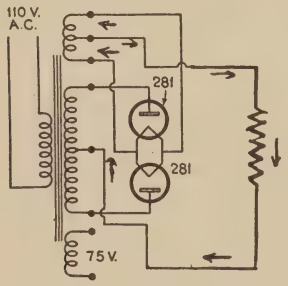
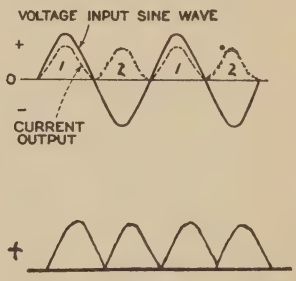


FIG. 92



FIGS. 93-94

of electrons. Whereas the normal two element filament type of rectifier is a highly evacuated tube which is free from air and gases, the high current rectifier tube contains a certain amount of inert gas which is deliberately introduced. Such gases are Helium, Argon and Neon. Their function is to supply some of the current carriers or electrons and thus aid in the function of the tube.

In tubes of this type, known as two element filament-gaseous rectifiers, the output current is high but the output voltage is low. In the regular two element filament type of tube previously considered, the output current is low, usually a maximum of 200 milliameters but the output voltage is high, in general practice as high as 1,500 volts.

The Tungar bulb representative of the one under consider-

ation is a two element structure, employed as shown in Fig. 95. The resistance designated as the "LOAD" represents the structure which is actuated by the current and voltage secured from the rectifier system.

The glass envelope of such a combination filament-gaseous type of rectifier is first exhausted of all air and gases, just as in the case of the 280 and 281 types of tubes. Then a certain quantity of the inert gas, usually Argon is introduced. The average pressure is about 10 millimeters of mercury. The introduction of the gas fills a definite purpose. Conductivity in this tube is based upon disruption of the molecular structure of the gas during the bombardment of the gas molecules by the electrons emitted by the filament. Each collision between an electron emitted by the filament and a molecule frees an electron from an atom and creates two current carriers instead of one. This continual state of agitation results in the production of a large number of current carriers which provide the high current required in the system. The blue or purple glow noted within such tubes when in operation is due to the ionization of the gas molecules, which means that the atoms of gas have either lost an electron or have acquired an extra electron. The presence of the glow indicates operation of the tube.

Such tubes are designated in a manner identical to the regular filament type of two element tube and are half wave rectifiers. In some cases two such tubes are employed in a full wave rectifying system.

THREE ELEMENT TUBES

DESPITE the great similarity between the two and three element tubes, the addition of the third element made possible, long distance telephony, radio broadcasting and sound motion pictures. The reason is simple and may be expressed in a few words. It provided a means of magnifying electrical energy millionfold, so as to convert a small electrical impulse into a powerful impulse without any change in character. The feeblest sound may be amplified to astounding proportions. The heart beat of a person may be amplified to sound like the firing of a cannon.

This element which converts a two electrode tube into a three electrode or element tube is a mesh structure located between the source of electrons (filament or cathode) and the plate. When the three electrode tube is shown in the form of a symbol it is very much like the two element tube but the grid is added as a zigzag line between the filament and the plate, as in Fig. 96. The designations F, G and P signify filament, grid and plate respectively. In some instances a ring encircles the electrodes as shown in the diagram. In other cases this ring is omitted. With respect to physical structure, various forms are used, as shown in Figs. 97 A, B and C. The formation of the grid depends upon the physical arrangement of the filament and plate. In Fig. 97A the filament is a straight wire or coiled spiral. The grid is also a spiral and encircles the filament. The plate is also a spiral and encircles the grid, and of course the filament. In 97 B, a grid structure is located each side of a double inverted V filament and a plate is located on the outside of each grid. In Fig. 97 C, the grid and plate are rectangular and encompass the filament retaining the relative positions as outlined.

To understand the action of the grid it is again necessary

to refer to the action of charges. Suppose we consider three charges, A, B, and C located as shown in Fig. 98. A is negative. B at the present bears no charge but is of such structure that A can pass through it. C is positively charged. The relative

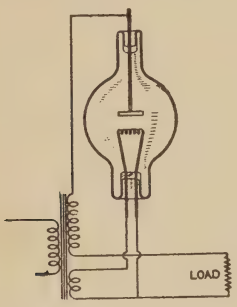
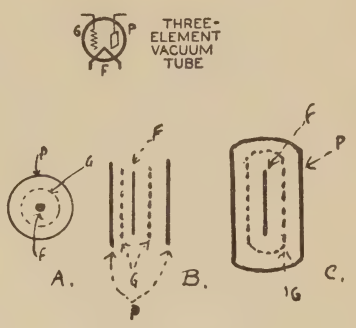


Fig. 95



Figs. 96-97

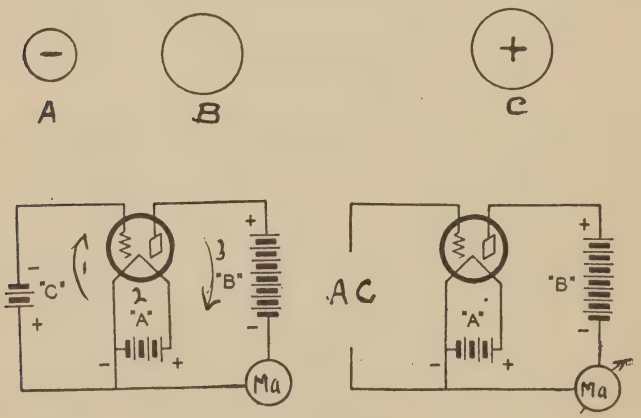
position of B and C with respect to A are as shown. B is located one third of the distance between C and A, away from A. In other words C is three times as far distant from A as B from A. Let us assume that the positions of B and C are fixed but A is free to move.

B bears no charge for the moment, however we know that unlike charges attract and like charges repel. If the charge upon C is sufficient, it will attract A or at least it will exert a pulling power upon A. If this power is sufficient, and B has no charge, A will be attracted to C. However if a negative charge is placed upon B, it is going to exert a repelling force upon A. During this time C is exerting an attracting force upon A. The effect of B and C upon A is governed by the intensity of the respective negative charge upon B and the positive charge upon C. However, the agent acting upon A is not only the relative charges upon A, but also the distance between A and B and A and C.

It has been found that electric force between two small charged bodies varies inversely as the square of the distance. This is quite significant with respect to the action of the grid

in the vacuum tube. If for the moment we assume like intensity of opposite charges upon B and C, with B negative and C positive, the effect of B upon A is going to be much greater than the effect of C upon A. To be exact 9 times as great, because C is one third the distance between C and A, from A. This means that, if A is an electron, it will not move to C, if the latter is the plate, because B which is the grid is exerting a controlling influence. Recalling the effect of distance upon electric force between charged bodies, the relation between B and A, and C and A is such, that the negative charge required upon B to counteract the pulling power of C upon A, is only one ninth of the intensity of the charge upon C. This, only because of the physical relation between the various charged bodies. Hence, in the illustration, the effect of B upon A is nine times that of C upon A.

Suppose now for a moment that B bears a positive charge. It will exert an attracting power, adding to that of C. If we assume that A cannot come to rest at B, the force of B upon



FIGS. 98-99-100

A, because of distance, with respect to the separation between C and A will again be nine times that of C.

Let us now proceed to the relation between charges and distance. Suppose that we wish to overcome the effect of the

difference in distance between B and A and C and A. Suppose further that B is again negative and is retarding the motion of A to C because the intensity of the charge upon B is the same as upon A. Since C is three times as far from A as B from A, and the effect of B upon A is nine times that of C upon A, it will be necessary in order that C overcome the influence of B, to increase the charge upon C to nine times its original value. If the original charge upon B and C was 9 units each, it will now be necessary to increase the charge upon C to 9×9 or 81 units, or the square of the ratio of distances. This condition of charges and distance is a very significant fact because it explains one of the properties of the vacuum tube and the function of the grid in producing that property of amplification. However let us continue.

Assuming that the charge upon C must be increased to nine times the charge upon B so as overcome the effect of B upon A because of the separation between the respective charged bodies, any change in charge upon B will necessitate nine times that much charge upon C in order to overcome the effect of B upon A. Thus by virtue of the relative positions of the charged bodies, the effect of B upon C is an amplification of the change in the charges upon B. This is true because a change upon B requires a much greater change upon C. Let us now apply this to practice.

We know that some sort of separation exists between the various elements within the tube. The exact separation is predetermined when the tube is desired to possess certain electrical operating characteristics. If we picture a circuit such as that shown in Fig. 99, we have a set of batteries whereby the "A" battery supplies the filament potential, the B battery applies a positive charge to the plate and a C battery applies a negative charge upon the grid. The polarity designations upon the respective batteries indicate the charges applied to the grid and plate respectively. The meter MA in the plate circuit of the tube indicates the flow of plate current.

Such a circuit is somewhat different than the two element tube arrangement. Now we find three circuits instead of two. 1, the grid-filament circuit; 2, the filament circuit; and 3, the

plate-filament circuit. The grid-filament circuit is usually referred to as the grid circuit and also as the input circuit. The plate circuit is referred to as the output circuit.

If the filament is heated to correct incandescence so that it emits electrons and the grid which is located directly in the path of these electrons, but is of such structure that the electrons may pass through its meshes, carries no charge and a positive charge is applied to the plate, electrons will flow between the filament and plate; current will flow between the plate and filament, through the circuit and will be indicated upon the meter MA. If with normal filament temperature and normal constant plate voltage, a negative charge is applied to the grid by means of the C battery, the repelling action of the grid upon the electrons, because of like polarity, will decrease the intensity of the electronic stream between the filament and plate. This action results in a decrease in plate current. If the magnitude of the negative charge upon the grid is increased, the plate current will decrease to a greater extent, until at some time, the magnitude of the negative grid charge will reduce the plate current to zero, although the filament temperature is normal and the plate potential is likewise normal. Such a state exists because the negative charge upon the grid prevents the flow of electrons between the filament and plate.

Thus the grid influences the number of electrons which reach the plate and the plate current. If on the other hand the grid is given a positive charge, it will augment the pulling power of the plate and increase the number of electrons which reach the plate. The increased number of electrons will then increase the plate current. However, the increase in plate current under such conditions will not be the same as the decrease in plate current when the grid is negative, because when the grid is positive, some of the electrons are attracted to the grid and do not move to the plate. Since the movement of electrons between the filament and plate means plate current, the movement of electrons between the filament and the grid will cause grid current. Thus when the grid becomes positive, grid current flows in the grid-filament circuit.

It is quite evident that with steady filament temperature

and constant plate potential, it is possible to cause a variation in plate current by simply varying the charge upon the grid. The magnitude of the plate current variation for a change of 1 volt upon the grid is a function of the design of the tube, that is its physcial structure.

What has been said is sufficient to indicate that with constant filament temperature and constant plate voltage, there is a definite relation between the grid voltage and the plate current, which in sum and substance is the effect of the grid charge upon the electrons, and considering the statements relative to charges and distance, is also the relation allied with the physical alignment of the various elements, that is separation between elements.

It might be well at this time, in order to facilitate comprehension of what is to follow later in the text to quote the various designations of letters employed to express terms. Each it will be found is allied with one of the three circuits mentioned some time ago in connection with the three element vacuum tube.

E = steady voltage
Eb = battery voltage (B battery)
Ep = effective voltage upon plate of tube
Ef = voltage upon filament
Eg = grid voltage (C battery)
e = instantaneous value of voltage
eg = instantaneous value of grid voltage
I = current
Ip = steady value of plate current
ip = instantaneous value of plate current

What has been said about the effect of the grid upon the plate current can be illustrated in the form of a grid voltage-plate current characteristic, wherein with constant filament temperature and constant plate voltage, the grid bias voltage or the charge upon the grid is caused to fluctuate, from say 1 volt negative to 1 volt positive. When neither positive or negative charge is applied to the grid, the latter is said to be at zero potential and without influence upon the electronic stream.

If it is possible to cause a change in charge upon the grid of a vacuum tube by applying first, a negative charge from a battery and then a positive charge from the same battery by reversing its connections or from a different battery, it is possible to apply this fluctuating charge by employing A.C. instead of the battery, as for example in Fig. 100. If the charge is varied 1 volt by means of batteries on A.C. voltage with a peak value of 1 volt will cause the same reaction upon the grid. Further if each change in the charge upon the grid causes a change in the plate current, a gradual change from positive to negative, such as will ensue when the input voltage is A.C., will cause a variation in plate current which will be a duplicate of the voltage wave form applied across the grid-filament circuit. As a matter of fact, it is not sufficient to say that the variation in plate current will be a duplicate. It will be an enlarged duplicate. The reason for the enlarged duplicate, is that the variation in plate current for a certain change in plate voltage, will be the same as if the plate voltage were changed a much larger amount to create the same effect as the smaller change in grid bias.

One of the interesting highlights developed thus far is that the application of a voltage to the grid causes a change in plate current in the plate circuit. Thus a voltage variation is converted into a current variation. Recalling what was said about the effect of changes in charges (see Fig. 98) the greater the change in voltage upon the grid, the greater the change in plate current because the greater the effect of the grid upon the electronic stream. The second significant fact developed at this time, is that power is not required in the grid circuit in order to have an effect upon the electronic stream and the plate circuit. Voltage and only voltage is necessary in the grid circuit. The vacuum tube is a voltage operated device.

The magnitude of signal voltage which may be applied to a vacuum tube is always limited by the grid bias and the bias voltage controls the input peak voltage and not input effective voltage. If a 2 volt bias is to provide an operating axis for a 2 volt effective grid swing, the actual voltage during the cycle

is not 2 volts but 2 × 1.414 or 2.828. The excess .8 of a volt would swing the grid positive.

Too much stress cannot be placed upon the importance of correct grid bias in an amplifying system. Experience with amplifiers has proved that a great deal of the distortion prevalent in audio systems, may be attributed to some condition which disturbs the grid bias voltage and the relation between the grid bias and the remainder of the voltages applied to a tube. The application and utility of a vacuum tube as an amplifier in any part of an installation is governed by three factors, grid voltage, filament voltage, and plate voltage. All of these voltages influence the length of the characteristic curve and the shape of the curve.

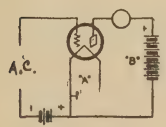


FIG. 100A

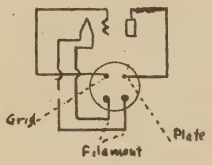


FIG. 100B

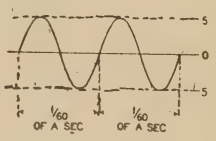


FIG. 101

Distortion is a function of the applied voltages allied with the input signal voltage. Insufficient grid, plate or filament voltages for any one input signal will cause distortion. Excessive grid bias on the other hand will also cause distortion. Excessive signal for normal filament, grid and plate voltages will likewise result in distortion and it is necessary to consider all of these factors, in addition to a few which shall be enumerated in due time.

At this time, one cannot help but wonder about that plate current variation. With a constant voltage applied to the plate, a steady value of current should be present in the plate circuit. This is actually the case. However the action of the changes in charge upon the grid when the signal voltage is applied reacts upon the electronic stream and causes a corresponding A.C. current variation in the plate circuit, mind you this current variation is now pulsating as in the case of the rectifier tube. This variation is A.C. and we can say, that an A.C.

current variation is superimposed upon the steady value of current normally in the plate circuit. This condition is evidenced when some D.C. current measuring device is located in the plate circuit. If the frequency of the signal voltage applied to the grid is so low that it is possible to note the increase and decrease and direction of the voltage, the current indicating device located in the plate circuit will show current variations. In other words the current will be found to increase and decrease exactly as the voltage applied to the grid increases and decreases. This means that the A.C. voltage in the grid circuit and the A.C. component of the plate current are in phase. However, if the frequency of the voltage applied to the grid is increased, so that it is no longer possible to observe the increase and decrease and direction of the voltage, it will be found when the adjustment of the tube operating potentials is such, that the plate current increases and decreases uniformily, that the current indicating device in the plate circuit indicates a steady value of current, the value found when the signal voltage is removed and just the grid bias is in the circuit. The reason for this action, is that the increase and decrease in plate current are the same, and since the current indicating device usually referred to as a meter cannot follow the rapid variations, the average change in plate current is zero and the meter indicates a steady value. Such a condition signifies distortionless amplification within the tube. If the plate current meter flickers, it shows that the circuit operating potentials are incorrect, or the input signal is excessive. In certain installations current indicating meters are located in the grid circuit of the amplifying tube. The normal indication should be zero current. If current flows, it means distortion in the amplifying system. The relation between the grid bias voltage and the input signal is such, that the peak value of signal voltage must not exceed the grid bias. The effective value of input signal voltage must not exceed .707 of the grid bias.

TUBE CONSTANTS

It is quite natural that there must be some relation between the grid bias and the plate voltage for each and every tube. One cannot increase the grid bias in order to allow increase input signal voltage unless the plate voltage is also increased. Further, each tube is designed to fulfill a certain function. Such functions are governed by the geometric structure of the tube, that is, the physical relation between the elements. Each separate relation between elements introduces a definite operating characteristic. One of the most prominent is the limitation of the input signal voltage into the tube. Another limitation is the magnitude of the plate voltage which may be applied to a tube. A third is the variation in plate current for a certain change in signal voltage. This characteristic governs the electrical energy to be found in the plate circuit as a result of the applied input voltage. Future reference to "grid bias" will mean the steady voltage applied to the grid to locate the operating axis and "input voltage" will designate the signal voltage fed into the tube.

We know that the plate current increases and decreases because of the input voltage. At any one instance "ip," the instantaneous value of plate current, must therefore represent some value of plate voltage other than the value applied by the battery, since at that instance "ip" differs from Ip the normal steady value of plate current without input voltage. If "ip" is greater than Ip, then the effect of the grid upon the plate circuit is to cause a condition representative of a voltage introduced into the plate circuit, which is additive to the normal steady voltage. If "ip" is less than Ip, then the effect of the grid upon the plate circuit is to create an effect such as the introduction of a voltage into the plate circuit which is subtractive from the normal steady value. Hence, the action of

the grid is to introduce into the plate circuit of a vacuum tube an alternating voltage and also an alternating current.

Amplification Constant

Let us now think back to our subject of charges as shown in Fig. 98. In order to counteract the action of charge B, it was necessary to increase the unit charge upon C because of its distance from A with respect to the distance between B and A. If the action of the grid causes a change in plate current which is the same as if the voltage upon the plate were increased or decreased by a certain amount, the action of the grid due to its location is to amplify within the tube. This amplification action is a function of the physical relation between the various elements. Hence for any one structure of a tube, that tube is possessed of what is known as an "amplification constant," since the grid of that tube will react in such a manner upon that plate circuit that the A.C. voltage produced in the plate circuit is greater than that applied to the grid.

For the sake of clarity we shall quote an illustration. Suppose that a tube has a filament, grid and plate, located in such relation to each other that the effect of the grid upon the electrons is 8 times as great as the effect of the plate. If a 1 volt A.C. signal is applied across the grid-filament circuit of the tube it will cause an alternating plate current in the plate circuit, with an instantaneous value of "ip" equal to a change of 8 volts in the plate voltage. There is therefore a relation between the change in grid voltage and a change in plate voltage to produce the same change in plate current. This ratio is an expression denoting the action of the relative charges upon the grid and plate with respect to their distance. This ratio is the amplification constant of the tube, usually designated by "μ" the Greek letter Mu. When applied in the form of an equation

$$\text{Amplification Constant or Mu} = \frac{\text{Change in plate voltage}}{\text{Change in grid voltage}}$$

The Mu, we stated is a function of the structure of the tube. As a matter of fact it is governed by the mesh of the grid, the separation between wires, the diameter of the wires employed for the grid and the distance between the grid and the plate. Since it is a function of structure and not of operating voltages, its value should remain constant independent of operating voltages. Generally speaking this is true in practice. If we are to be exact, the value of Mu does change with operating potentials but the change is very small. It drops slightly at low values of plate voltage and at high values of grid bias. This change however is entirely negligible. Thus we have completed our first tube constant.

Upon first consideration one can imagine the application of tubes with high values of amplification constant or Mu and the attainment of a high degree of amplification. One can further picture the possibility of an arrangement where a few tubes of high Mu can be employed to produce the amplification now available with many more tubes of lower Mu. The value of Mu possessed by any one tube introduces a definite limitation with respect to the utility of that tube, that is its position in an amplifier which is the equivalent of a limitation in the permissible signal input. The reason for this limitation is as follows:

The illustration of charges showed how the effect of the grid was multiplied in the plate circuit. The extent to which it is multiplied is the Mu of the tube or the structure of the grid and the distance between the grid and plate. The greater the Mu of the tube, the greater is the effect of the grid upon the plate circuit. Since a change in grid voltage causes an effect similar to a change in plate potential, the actual voltage upon the plate which is effective in producing the plate current flow, by virtue of its attracting power upon the electrons, notwithstanding the presence of the grid, is some value less than the voltage applied by the battery. The magnitude of reduction of the plate voltage although the battery voltage remains constant is of course a function of the negative charge applied upon the grid or the grid bias.

The higher the amplification constant of a vacuum tube the less can be the grid bias and the signal input. This means that high Mu tubes must be employed in that part of the installation subject to low input voltages, which enable the use of low bias voltages.

Plate Resistance and Impedance

The passage of the electrons from the filament to the plate must of necessity represent some work done on the part of the electrons. All are moving in one direction and being of like polarity exert a repelling action upon each other. This action is quite prominent and constitutes a large part of the expenditure of energy on the part of the electrons when moving from the filament to the plate or from the anode to the cathode. This expenditure of energy is represented by the heating of the plate. The expenditure or loss of energy is the equivalent of a resistance, and each tube is said to have resistance as one of its electrical constants. The flow of electrons is between filament and plate and this resistance is therefore represented as being located between the filament and plate and is known as the plate-filament resistance, or the plate resistance, or the internal resistance of the tube. It is however customary to refer to the plate resistance or the internal resistance of a tube as the impedance or plate impedance.

We stated that a steady value of plate current is found when a steady voltage is applied to the plate and no input voltage is applied to the grid. The relation between Ep and Ip is then the D.C. resistance of the tube, *i.e.*,

$$\text{D.C. resistance} = \frac{Ep}{Ip} —$$

However we now find that when an input voltage is applied to the grid of the tube, we have A.C. voltage and current in the plate circuit, which condition introduces an A.C. resistance. In other words the A.C. resistance of the tube is then

$$\text{A.C. resistance} = \frac{ep}{ip}$$ or the ratio between instantaneous

values of A.C. voltage and current in the plate circuit. As it happens, the plate resistance or plate impedance value referred to in all text and other data is the A.C. resistance of the tube. This resistance functions in the nature of a pure resistance and as far as the frequencies encountered in audio systems are concerned, this impedance remains constant regardless of frequency. It too, is expressed in ohms.

The plate impedance of a tube cannot be determined in a simple manner, but its value is governed by the distance between the filament and plate. If the distance between the plate and filament is reduced, the plate resistance or impedance is reduced. Such condition however also reduces the distance between the grid and plate, since the grid is between the filament and plate, so that the amplification factor of the tube is also reduced. If an effort is made to increase the amplification factor of the tube by increasing the distance between the grid and plate, the distance between the filament and plate is automatically increased, hence the plate resistance, designated as "rp" increases with each increase in amplification constant or Mu.

In practice, that is in use, the value of "rp" is independent of the signal voltage but varies inversely in a non linear manner with the plate voltage, decreasing as the plate voltage is increased. The decrease varies in an exponential manner, *i.e.*, is greatest for small increments of plate voltage increase from a definite minimum and then decreases more slowly as the normal plate voltage is increased. It also increases with each decrease from the normal value of filament temperature or reduction in electronic emission. The less the emission, the greater the plate resistance.

We stated earlier in this chapter, that the plate impedance of a tube is a ficticious resistance within the tube. Bearing in mind that it is within the tube and that we have A.C. current and voltage, the A.C. current in the plate circuit is governed to a large extent by the plate impedance, that is, the magnitude

of the current change in the plate circuit per volt change upon the grid. Hence a certain amount of power is lost within the tube and a certain voltage drop occurs across the plate impedance of the tube. Since this drop is within the tube it serves no purpose as far as the utility of the tube is concerned. Hence an effort must be made to minimize the voltage drop across the plate impedance of the tube.

Mutual Conductance

The relation between the Mu of a tube and its "rp" presents a case wherein we have a resistance which controls the current in a circuit when a voltage is applied. This relation is

$$Ai = \frac{Mu}{rp}$$

The value of Mu represents the A.C. voltage introduced into the plate circuit by the action of the grid and "rp" represents the resistance in the plate circuit within the tube, so that the above relation represents, if we assume a unit change of charge upon the grid, say 1 volt, the current output per volt input, expressed as Ai. We find however that the above expression also represents another tube constant, namely Mutual Conductance, designated as Gm and expressed in Mho, the reciprocal of the ohm. The complete equation is

$$\text{Gm in Mho} = \frac{Mu}{rp}$$

However the value Mho is too great for everyday practice and the term micromho is used which changes the above equation to

$$\text{Gm in micromhos} = \frac{Mu}{rp} \times 1{,}000{,}000$$

The expression mutual conductance is employed to indicate the merit of a tube and since it is the ratio between the change

in grid voltage and the change in plate current, the term Mho is nothing more than the reciprocal of that resistance which governs the change in plate current for a change in grid voltage.

A very significant fact allied with the mutual conductance constant of a tube, is that the method used to determine this constant in normal practice, is actually the best method of testing a tube, to determine its merits for use as an amplifier or any other function. The reason for the above, is that every factor allied with the tube is taken into consideration in the formula Mu ÷ rp and that the test is made under conditions which simulate actual operation of the tube.

Investigation of the formulæ involved in the aforementioned computation shows that the tube with the highest mutual conductance affords the greatest variation of A.C. current flow in the plate circuit for a unit change of grid potential. Since the basic function of the vacuum tube is to convert input voltage into output current or at least into A.C. current in the plate circuit, a high value of mutual conductance signifies a good tube. It is necessary however to state, that comparison by means of mutual conductance can be accomplished only when the tubes under observation are of like character and intended for similar service. Tubes of unlike character intended for remote parts of a system should not be compared according to their respective mutual conductance values. The results will be erroneous.

The consideratoin of mutual conductance shows that a high Mu and a low "rp" if possible of attainment provide the best operating conditions, consistent of course with the input voltage requirements of the tube, since the higher the Mu, the less the permissible voltage input. This fact is borne out in practice. Tubes intended for similar service as evidenced by commercial output are of such design that the greater the permissible input voltage, the lower the Mu of the tube.

We place a great deal of stress upon mutual conductance because we feel certain that interest is rampant as to the best method of testing a vacuum tube which is in service. Many constants have been recommended as a basis, yet none approaches the mutual conductance in beneficial value.

STRUCTURE OF FILAMENT CIRCUITS

A.C. Filament

The A.C. tube, that is the tube designed for operation with A.C. filament potential does not signify that its remaining operating potentials are also A.C. While it is possible to secure the required D.C. grid and plate voltages from an A.C. source, grid and plate potentials are identical in all classification of amplifying tubes. This does not mean that all values of grid and plate voltage are identical, since the exact voltage applied to the grid or to the plate is a function of the design of the vacuum tube and its mode of utility. However, the filament circuit of the A.C. tube differs from that of the regular D.C. tube and the changes involved must be understood.

We are going to assume that the reader is acquainted with the general structure of the conventional 3 element vacuum tube.

The A.C. 3 element tube, differs from its D.C. prototype in but one respect, the design of the filament circuit, the former being designated for the application of alternating current to the filament whereas the latter is designed for direct current. The grid and plate structures of A.C. and D.C. 3 and 4 element tubes are identical. Consequently perfect filament circuit design of the A.C. tube permits its use as a replacement tube wherever a D.C. tube was previously employed. One qualification is necessary—certain circuit wiring alterations being necessary when the A.C. tube is employed.

In direct contrast to the tube with a filament designed for direct current, the tube designed for alternating current filament operation is not limited solely to alternating current; D.C. potentials being equally suitable. That this is true is evidenced by the general use of the 171, the 210 and the 250, the 105D, the 205D tube with A.C. and D.C. filament poten-

tial. The general run of tubes utilizing thoriated tungsten filaments specifically designed for direct current filament operation are unsuited for A.C. filament potential, the results being unsatisfactory when alternating current filament supply is used.

A survey of the A.C. tubes in use today shows two classifications of filament circuit structures. One is the conventional filament type and the other is the heater type. Let us discuss them individually and consider first the conventional filament type since the structure of this filament differs from the filament in a D.C. tube in only thickness and material. We refer to the filament of the 226 type tube of standard design and utilizing four prongs, two of which are the terminals for the filament, the third is the terminal for the grid and the fourth is the terminal for the plate, conditions identical with that found in the case of the D.C. conventional filament type of vacuum tube as shown in Fig. 100B.

A.C. excitation of a vacuum tube filament introduces considerations not encountered when D.C. potential excitation is employed. In contrast to D.C. potentials, A.C. potentials are not constant but fluctuate between zero and a maximum value of a period equal to twice the frequency of the line supply. Reference to the accompanying illustration Fig. 101, of a few cycles of A.C. shows how the voltage varies instantaneously with respect to time. If we assume the drawing to illustrate a few cycles of a transformer output at a frequency of 60 cycles we note that the voltage rises from zero to a maximum and then decreases again to zero, 120 times each second or twice during each cycle. Hence we have the instantaneous voltage variation with respect to time. The applied voltage also causes current flow which in a pure resistance such as a vacuum tube filament varies directly as the voltage, rising to a maximum and decreasing to zero 120 times a second. The rapidity of the rise and fall is governed by the frequency of the line supply and we select 60 cycle supply as illustrative because it is most common in power circuits employed today. The data quoted with respect to the filament operation is however, applicable to all other commercial power supply frequencies.

Suppose that we assume A.C. supplied to the filament of a vacuum tube by means of a transformer output winding with the primary connected to a power supply line.

Since the function of the filament is to be the source of electrons and the number of electrons emitted from the filament or the filament emissivity is governed by the temperature of the filament, it stands to reason that the filament must be of a type which will retain its heat at a maximum value during the period of current fluctuation. In other words the filament must be of such material and structure that the heat generated or the temperature of the filament when the current is maximum will diminish very little while the alternating potential and consequent current are approaching zero and again rising to a maximum during the next cycle. This required property is "filament temperature stability."

Stability of filament temperature is a function of three factors—temperature of the filament—the mass of the filament and the surface area. The temperature of the filament is of importance since the heat radiation losses are proportional to approximately the fourth power of the temperature. Hence the lower the temperature, the less the heat radiation losses and since the heat radiation losses become of importance as reasons for the rapid dissipation of the filament heat during the decreasing half of each half cycle of voltage and current, the lower the initial temperature, the less the heat radiation losses and the greater the filament temperature stability. Temperature stability is also a function of the ratio between these two factors, the greater the ratio between these two factors the greater is the heat storing capacity of the filament with a fluctuating current flow.

Voltage Variation Hum

Elimination or at least minimization of the temperature variation hum was not the only reason necessitating the re-designing of the filament of the A.C. tube. Another consideration of equal importance was the voltage variation hum. Reference to the accompanying illustrations Figs. 102 and 103 aid in

the comprehension of the phenomenon. In Fig. 102 we see a vacuum tube circuit structure consisting of the plate, grid and filament. The filament excitation is obtained from a 6 volt storage battery. A potentiometer or voltage divider shunts the source of "A" potential. A grid bias battery "C" and a B battery are connected as shown.

With a constant source of excitation, each section of the filament has a definite voltage relation with respect to some other section. Considering the two extremities, one is 6 volts positive with respect to the other, and considering the other extremity, it is 6 volts negative with respect to the former. If we select as a point of observation, the midtap of the filament shunt potentiometer, one filament extremity is 3 volts positive and the other extremity is 3 volts negative. If we now take into consideration the emission from the filament with respect to the grid, we find that in the arrangement shown in Fig. 102, the potential difference between the grid and the extremities of the filament has a definite relation. The portion of the grid which is nearest the extremity of the filament rated at 3 volts positive with respect to the midtap, has a 6 volt voltage difference because of the additive effect of the 3 volt negative grid bias. On the other hand, the section of the grid nearest the filament rated at minus 3 volts with respect to the midpoint of the filament has a zero voltage difference because of the bucking effect of the 3 volt negative C voltage.

If we now reverse the polarity of the filament battery, the voltage differences of the filament extremities with respect to the midtap and the voltage difference between the grid and the filament will still be 6 V. and zero V. but reversed in position. If we can realize a rapid reversal of the polarity of this filament battery, we can visualize a continual reversal of the voltage difference between the grid and filament, each end alternating between 0 and 6 volts.

These potential difference variations between the grid and the filament and one end of the filament with respect to the other, manifest an influence upon the electronic flow, with respect to the filament and plate, in fact, the positive end of the filament acts like an attacking force for the electronic emission

taking place at the negative end. It is therefore easy to comprehend that the greater the excitation voltage, the greater the previously mentioned effect. This is one of the reasons for the pronounced use of low filament voltages for A.C. tubes.

A close analysis of the conditions existing when the potentiometer is adjusted for the exact center connection will facilitate comprehension of the phenomenon present when the shunt potentiometer is adjusted for an "off center" position of the tap. If the potentiometer tap is off center, the potential difference between the two filament extremities and the potentiometer tap is not uniform because the slider on the potentiometer applied as shown, is equivalent to a direct tap along the length of the filament.

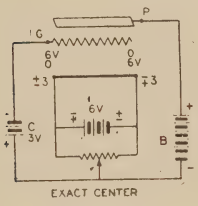


FIG. 102

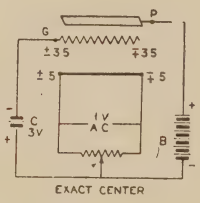


FIG. 103

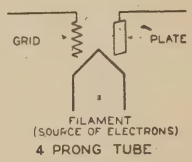


FIG. 104

If we now supplant the D.C. source of potential with an A.C. source of potential as shown in Fig. 103 and retain the exact filament shunt potentiometer tap return connection, we find the two filament extremities alternately positive and negative. If the applied voltage is 1 volt, each extremity of the filament is, with respect to the midtap, alternately .5 volt positive and negative. With a constant negative bias of 3 volts, both ends of the grid maintain with respect to the filament extremities, a potential difference of 3.5 volts. With uniform potential difference between the grid and the filament, satisfactory operation is easily available; but if the shunt potentiometer tap return control is adjusted for an off center position the potential difference between the two filament extremities and the potentiometer tap is no longer equal. This arrangement produces two detrimental effects. First, we have an unbalanced state of

potential difference between the grid extremities and the filament extremities with the result that the electronic passage between the filament and the plate through the control grid is not uniform during the cyclic variations of the applied filament potential; resulting in a hum of twice the applied frequency. Second, the grid effect of the filament is the attracting force of one end of the filament with respect to the other as previously explained, and is present to a much greater magnitude, and during the cyclic variations of the applied potential, produces a very decided hum in the output. It is therefore, self-evident that an electrical balance in the A.C. filament circuit is imperative. The grid return and the plate return must connect to the point of average filament potential; otherwise the effective grid bias and the plate potential vary during the alternations of the excitation voltage in accordance with the voltage difference between the two filament extremities with respect to the midtap location. The attainment of an electrical balance in the filament circuit is the reason for the provision of a midtap for the filament transformer winding and for the suggested use of a center tap resistance across the filament terminals of the conventional A.C. tube.

Types of A.C. Tubes

The general run of A.C. tubes available at the present time is divided into two groups, one being known as the filament type of A.C. tube and the other as the heater type of A.C. tube. Expressed schematically, the structure of the filament type of A.C. tube is shown in Fig. 104 and is identical to the conventional D.C. type. As is evident, this tube is suitable for insertion into the conventional 4 prong tube socket. This type of tube is representative of the 226, the 210, 250, 205D, 852, 211E, etc. The filament is a short, thick structure and consists of a base such as platinum coated with oxides of barium and strontium. The platinum of commercial quality functions as the core and carries the heating current which in turn heats the oxide coating, the source of electrons. A discussion of the various designs of this type of tube is unnecessary since all

are of practically identical design and are used in like manner when applied to a circuit.

In contrast to the filament type of A.C. tube, we have the heater or cathode type of A.C. tube, the schematic structure of which is shown in Fig. 105 and is representative of the 227 tube. A comparison of Fig. 100B and Fig. 105B brings three significant facts to light. First, that the grid and plate structures are alike. Second, that the filament circuit of the heater type of tube consists of two elements rather than one, in the case of the filament type of tube. Third, the heater type of tube employs four elements and has five prongs, necessitating the use of a five prong socket. The fourth element in this tube is a cathode, an oxide coated electron emitting cylinder, which surrounds the filament and is insulated therefrom. In direct contrast to the filament type of A.C. tube, wherein the incandescent filament is the electron emitter, the electron emitter in the heater type of A.C. tube is the cathode. The filament functions solely as the heater whereby the cathode temperature is raised to the operating value. The cathode is therefore indirectly heated, and requires from 7 to 30 seconds, before it reaches the correct electron emitting temperature.

Reference to previous illustrations of the D.C. tube shows that complete input and output circuit continuity is necessary in order that the tube function in normal manner. We have found that one side of the D.C. filament in the D.C. type of tube is the point of common connection for the B minus and the grid return lead. With respect to the latter, since all of the tubes employed for amplification employ grid bias voltages, the side of the filament which is connected to the B minus is also the side employed for connection to the C plus side of the grid bias battery or its equivalent if the grid bias voltage is secured from some other source.

It is therefore logical that some such common return point must be found when A.C. current is supplied to the tube filament. This point is the electrical center of the A.C. filament circuit, represented by the position of the filament shunt potentiometer slider in Fig. 103. In some instances such electrical balance, for it is nothing more than a balance, is secured by

the use of a fixed filament shunt resistance with a fixed midtap, or the midtap on the filament winding of the transformer which supplies the filament voltage.

An analysis of Figs. 102 and 103 shows that the filament in each case is a part of the grid and plate circuits. This is of course natural when one considers that the filament is the

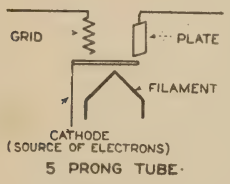


FIG. 105

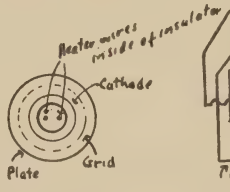


FIG. 105A

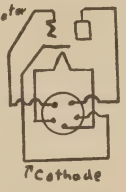


FIG. 105B

source of electrons, and that these electrons act in both the grid and plate circuits. But what about the filament employed in the cathode type of tube. Here the filament or heater is NOT the source of electrons. It simply heats the cathode which is the source of electrons, hence the cathode must be the point of common return. In contrast to the A.C. filament, the cathode is a different structure, one which cannot be shunted with a resistance so as to secure electrical balance. Such balance is actually not essential in this circuit because the potential variations present in the filament are not transmitted to the cathode. That is, the general assumption for operation is that such is the case. It is assumed that the flow of electrons from the cathode is uniform as if the element were D.C. operated. Hence whatever connections in the grid and plate circuit of the cathode or heater type of vacuum tube are to be made to the point of common potential are made to the cathode. This element is the return for the B minus lead of the plate voltage applied to the tube and is the return for the C plus lead of the grid bias applied to the tube.

What has been said should not be construed as meaning that there is no relation between the cathode and its associated heater circuit. There is present between the heater and the

cathode of that tube a definite field. In some cases it is of little importance whereas in others depending upon the utility of the tube, this field gives rise to a hum in the plate circuit. It is therefore common practice to locate the electrical center of the heater circuit and make that common as well as the cathode. Whatever the specific circuit arrangement, the center tap of the heater circuit eventually makes contact with the cathode. It is customary to locate this point of electrical balance in the filament circuit at ground potential, by connecting it to the grounded part of the complete system. Figs. 106, 107, 108 and 109 illustrate the methods employed to connect to the common return point of electrical balance in the filament circuit of the filament type of A.C. tube and in the cathode type of A.C. tube. Figs. 106 and 107 illustrate the center tapped filament transformer and center tapped filament shunt resistance respectively, whereas 108 and 109 show the cathode type of tube.

While it is generally assumed that the current variation in the filament or heater of the cathode type of tube does not cause hum, it is still necessary to remember that an electric current will cause a field around a conductor. However the temperature variation of the cathode, by virtue of the temperature variation of its heater, is very much less than the temperature variation of the conventional A.C. filament, hence less difficulty

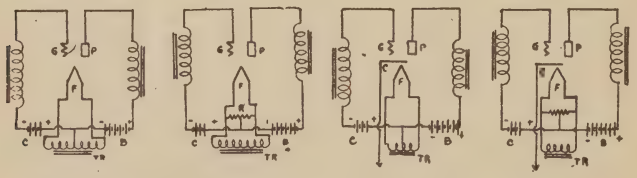


Fig. 106 Fig. 107 Fig. 108 Fig. 109

is experienced with hum, due to incorrect electrical balance in the filament circuit and disturbed balance between the grid-filament and plate-filament circuits. Expressed in a different manner, it means that less care is required to adjust the electrical balance of the cathode type of tube (the —27) than the balance of the filament type of tube (the —26). On the other

hand it also means that hum in a system employing such tubes may be due to incorrect electrical balance or an imperfect filament shunt resistance. Greater care must be exercised in the case of the filament type of tube. This however does not apply to the output tubes in an amplifying system. More will be said on this score as we progress with the text.

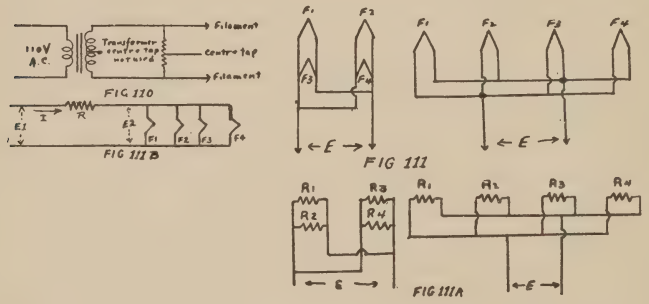
Such difficulties are not encountered in D.C. circuits because the voltages are steady, but much trouble is actually experienced in an A.C. filament circuit and particular stress must be placed upon the item. This is so because a defect in the electrical balance does not manifest an effect upon the remainder of the electrical circuit. By effect we mean some change which may be detected because it influences actual operating potentials.

Acknowledging the fact that a correctly adjusted filament shunt resistance is required for the filament type of A.C. tube and that a similar, but not necessarily as accurate center tap must be found for the cathode type of tube, it does not signify that one such adjustment suffices for all tubes. This item is of importance. It is true that various tubes of similar type may be interchanged with entire satisfaction, but one cannot make a set rule to that extent. The same applies to filament transformer center taps. The fact that the transformer winding is correctly tapped with respect to the number of turns in the winding, does not mean that, that circuit is actually balanced. The midturn of a winding is not always the center tap, in which case it is necessary to ignore the center tap and to apply a resistance, tapped at the center with a variable slider which allows adjustment for any condition. This is shown in Fig. 110 and is quite an important point.

Formation of Filament Circuits

Generally speaking more than one tube is employed in an amplifying system. While it is possible that a certain amplifier employs but one tube in a certain unit, other tubes in that system may be operated from the same source of potential. Considered from an electrical angle, the filament of a vacuum

tube or the heater filament, is nothing more than a resistance. It is true regardless of the type of tube involved, whether it is designed for D.C. filament operation or A.C. filament operation. Since current must flow through these resistances (filaments), a certain method of connection to a source of potential must be used. The exact method depends upon the formation of the circuit and the conditions under which the filaments are to be operated. Thus we have parallel filaments and series filaments. It should be understood that the significance of the parallel or the series connection is one allied with the manner in which the filaments of the various tubes are interconnected and not



FIGS. 110—111B

with the actual filament structure within the tube. This can be best comprehended by assuming each tube filament to be a resistance carrying current due to the application of a voltage from some source. This is shown in Figs. 111 and 112, with the equivalent electrical circuits in 111A and 112A. Fig. 111 shows four filaments in parallel connected to a source of electric potential. The same formation applies with equal facility to A.C. as well as D.C. The formation of the circuit has a bearing upon the current flow and the voltage required to actuate the filaments. Reference to the law for parallel circuits, the voltage is the same across the various branches of the circuit, hence if these tubes are of like character the voltage required to operate one tube is the same as the voltage required to operate any number of tubes of similar filament design.

However, the total resistance of a number of parallel resistances is less than the resistance of any one section, and if all the tube filaments are alike, the equivalent resistances are alike. Therefore the total resistance of four tube filaments is less than one tube filament. Since the combined resistance is less than that of one, the current flow will be greater, varying inversely as the resistance. Hence in a parallel circuit the voltage remains constant, but the current consumption increases as the number of tubes increases. If we say that the voltage and current requirement of F1 is 1.5 volts and 1.05 ampere (the —26 type of tube) and four such tube filaments are connected in parallel, the voltage requirement remain at 1.5 volts but the current consumption is 1.05 $\times$ 4 or 4.20 amperes. If the source of voltage is A.C., the above current and voltage values are the effective or r.m.s. values.

Mention must be made to the effect that the method of indicating the physical relation of the tubes has no bearing upon their interconnection. Tubes need not be adjacent to each other in order that their filaments be connected in parallel. Furthermore the operating voltages applied to the plate of the tube, or the grids of the tubes, or the method of employing the tube has no bearing upon the parallel connection of the filaments. The only important requirement is that the voltage specifications for the filaments be identical. The current requirement is of no consequence, since the current flow through each branch will depend upon the resistance of that branch. The resistance of a tube filament is equal to its rated voltage divided by its rated current.

The situation may arise when the source of voltage is in excess of that required. In such an event it is necessary to reduce the voltage supplied to the tube filaments connected in parallel. Since the final solution of a number of resistances (filaments in parallel is the same as if all were combined to constitute a single resistance of correct value), the final circuit evolves into a series circuit, where one resistance is employed to "drop" the voltage to the correct value so that the final drop across the parallel network is the value required. Such a system is shown in 111B.

It is evident, particularly when the law governing voltage in parallel circuits is considered, that tube filaments of like voltage requirements may be connected together.

Series Filaments

Another method of connecting tube filaments is shown in Figs. 112 and 112A. This is the series connection, where all of the filaments are connected in series. This arrangement is identical to the system discussed in connection with Ohm's Law applied to series circuits. Appreciating that the current requirement of the four filaments is the same, the voltage required to force a certain value of current through a resistance is pro-

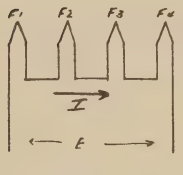


Fig. 112

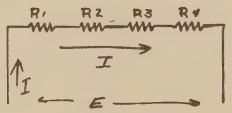


Fig. 112A

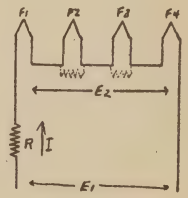


Fig. 112B

portional to the resistance, hence the voltage E in Fig. 112 must be four times the voltage required to cause correct current flow through one of the tube filaments. In contrast to the parallel circuit, the series filament circuit entails a value of current equal to that required by one tube, since current is the same in all parts of a series circuit as shown in Fig. 112A. The voltage drop across each R1 is equal to the I $\times$ R or the current flowing through the filament times the resistance of the filament. Hence the voltage increases in the series circuit, and the total voltage required is the sum of the individual filament voltages. The only requirement in such a circuit is that the current consumption of all tube filaments be the same.

As in the case of the parallel system it is possible that the output voltage of the source of filament potential is in excess of the voltage required by the series combination. Once again

a separate series resistance may be employed, as shown in Fig. 112B and designated as R. As in the case of parallel circuits, the series filament arrangement has no bearing upon the utility of the vacuum tube or its application, that is the form of amplification or the type of devices located in the grid or plate circuits of the tube. However, it is not customary to operate A.C. tubes in series filament connection. Some D.C. installations employ series filament arrangements, but many others employ the conventional parallel method of connection.

Nothing in a system limits the choice of filament circuit wiring to either the parallel or the series arrangement. Many complete units encompass both, some of the amplifiers being wired with series filaments operated from D.C. and other units in the same amplifier being wired for parallel filament operated from A.C.

With respect to the series combination, an open filament will open the remainder of the circuit and current will not flow. In the event that one or more of the filaments in the combination is shunted by a resistance as indicated by the dotted lines, removal of one of these tubes may cause injury to the other filaments because of an increase in current flow.

A.C. Filament Circuits

The problem of A.C. filament circuits differs very little from D.C. circuits, that is insofar as the calculation of the filament control resistance is concerned. Here we are concerned with A.C. tubes and transformers as sources of filament potential.

The factors present in A.C. filament circuits are such that the calculations of resistance necessary to produce a definite voltage drop are identical to that present in D.C. circuits, because the factors of reactance and impedance, which are normally present in A.C. circuits, are absent in the filament circuits. Whatever has been said about the calculation of any one filament control resistance in a D.C. filament circuit, is applicable to A.C. filament circuits despite the fact that a transformer supplies the filament potential. However, the fact that the source of filament potential is a transformer and in

view of the fact that such transformers possess definite operating characteristics and limited current output values, in contrast to the average storage battery when employed with the average amplifier, we must of necessity delve into the details associated with such transformers.

A discussion of the filament transformer is necessary in order that complete comprehension of the filament circuit be obtained. Whereas the average storage battery possesses more than the required current output, the filament transformer for use in A.C. amplifiers possesses a limited output. This is also true in the case of the A eliminator. The filament transformer utilized to supply the excitation voltage for the A.C. tube filaments, consists of a closed core upon which are wound several windings. One of these is the primary or input winding and the other or rest as the case may be, supply the various filament voltages.

Following standardization of A.C. filament tube voltages, a similar progress of standardization ensued among transformer manufacturers with the result that the average filament transformer is designed to produce a definite current and voltage output. The number of secondary or output windings of a filament transformer is governed by the precalculated utility of the transformer. Just as the number of windings are predetermined, so are the number of tubes of like filament potential requirements which may be operated from any one winding. In other words, each winding possesses a definite wattage rating, which is the product of the voltage rating times the maximum current output. The wattage drain applied to the transformer winding consists of the load constituted by the filament voltage and current requirements of the tube filaments connected to the transformer.

It is customary to rate transformers by quoting the sum total of the watts output of the various windings. In this respect, it is important to remember that the windings considered are the output windings and not the input winding. In some instances where only one output winding is available, the wattage rating is applicable to this one winding. Suppose that we have a transformer rated at 7.5 volts and 75 watts.

The maximum amount of current available from such a transformer would be 75/7.5 or 10 amperes. Let us further imagine that the filament requirements are such that the voltage is 7.5 volts and the current is 2.5 amperes. Comparing the above figures with the current output of the transformer, we note a discrepancy of 7.5 amperes and one would believe that some sort of resistance is necessary to dissipate the available current in excess of the value required. Such however, is not the case. The fact that the maximum current output of the transformer is 10 amperes and that we are only drawing 2.5 amperes, does not mean that the output voltage will be 30 volts or 75/2.5 which is the equivalent of the wattage divided by the current load. The output voltage will remain constant at approximately 7.5 volts because the design of the winding is such that the output is 7.5 volts. The rating in watts when associated with a definite voltage means that any amount of current within that wattage rating is available. Hence, the filaments in question may be connected directly to the transformer winding without any series resistances. In some instances, the output voltage of a transformer winding is in excess of the rated value when the current load is less than the rated maximum. This must be borne in mind and is one reason why a tube should not be removed from the socket when several other tubes are being supplied with filament voltage by the same transformer winding.

Suppose that this transformer is to operate a number of 5 volt tubes. Here we find a situation similar to the battery operated arrangements where the source of potential possesses a rating higher than the required filament potential. In this instance, it is necessary to employ a series resistance, calculated as mentioned in the D.C. systems. In contrast to D.C. systems, the position of the voltage reducing resistance is an important subject in A.C. filament circuits. Because of the requirement for electrical balance in the filament circuit of A.C. tubes, these resistances can be placed only at certain points in the circuit. If the tube in question or the tubes in question as the case may be, are operated from a center tapped filament transformer and the center tap is employed it is necessary to

employ two voltage reducing resistances, one in each leg of the winding. The value of each one of the resistances is then equal to one-half of the total resistance required. For example, we have a 7.5 volt midtapped winding which we wish to use as a source of filament potential for a 227 type tube requiring 2.25 volts, at 1.75 amperes. With an available voltage of 7.5 and a required voltage of 2.25, we must dissipate the difference of 5.25 volts. The value of resistance required to effect this result is 3 ohms. Since we wish to preserve the electrical balance secured by the center tap, we must add equal resistances into each leg of the filament circuit, consequently we need two 1.5 ohm resistances capable of carrying 1.75 amperes.

The use of voltage reducing resistance in a filament circuit utilizing a tapped filament winding, would mar the electrical balance of the circuit and increase the possibility of hum. This is particularly true with the 226 type of A.C. tube.

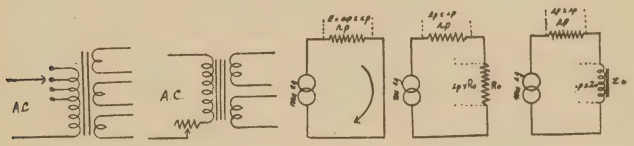
A single filament control resistance as in D.C. circuits, is applicable when the filament balance is secured by means of a center tapped or rather a variable center tapped resistance R of the potentiometer type, in place of the tap on the transformer winding.

Mention of versatility of location should not lead one to believe that the filament voltage reducing resistance can be located between the shunt resistance and the filament terminals. Connecting a rheostat or a voltage reducing resistance, between the filament shunt resistance or the electric balance producing resistance and the socket filament terminals, disturbs the balance of the filament circuit and is incorrect.

With respect to the voltage rating of a filament winding when calculating the value of filament control resistances, it is imperative to remember that the available voltage is that across the two outside leads, in the event that it is a center tapped transformer. The presence of the center tap has no bearing upon the voltage but it provides a means of utilizing a portion of the winding, if the arrangement eliminates the necessity of a voltage reducing resistance. An example of this is the use of one-half of a center tapped 5 volt winding of suitable current output to supply a 2.5 volts potential to a 2.5 volt filament. It

is however, possible to satisfactorily employ a filament winding of any potential to supply the filament potential for a tube or a number of tubes requiring an excitation voltage lower than that of the filament winding, providing of course, that the current output of the filament winding is sufficient to fulfill the needs of the tube or tubes as the case may be. An example of this is the use of the 7.5 volt winding for a 2.25 volt tube mentioned earlier in this section.

At this time it is necessary to mention the line voltage input because it manifests an effect upon the voltage reducing resistance employed in the filament circuit. The normal range of line voltage available in various parts of the country is approximately 30 volts, being between 100 and 130 volts. Measurements made upon various transformers show distinct variations



FIGS. 116—118B

in output voltage. In some cases the voltage output of the 1.5 volts winding, reaches 1.8 volts, the voltage output of the 2.5 volt winding reaches 2.9 volts and the 7.5 volt winding reaches 8.3 volts. This increase in voltage is not the fault of the transformer manufacturer. The average transformer is manufactured for operation at an input voltage between 110 and 115 volts and when operated at higher potentials affords excessive output voltage values. This condition is greatly aggravated when the maximum current output is not realized. The calculation of the correct resistance required in A.C. filament circuits involves the process described before, and in addition, necessitates the determination of the transformer output voltage. Reference is made in practically every amplifier test, to the line voltage during the period of test.

VOLTAGE AMPLIFICATION

THE purpose of the vacuum tube as an amplifier is to magnify the electrical equivalents of sound.

We stated that the application of an alternating potential to the grid of the vacuum tube, that is across the grid filament circuit, will cause the flow of alternating current in the plate circuit, just as if an alternating voltage had been introduced into the plate circuit to act upon the steady plate potential. The actual value of this potential is a matter of tube structure. The actual value of the A.C. component in the plate circuit involves both the factor which governs the voltage introduced into the plate circuit and the factor, plate resistance which governs the exact value of current in the plate circuit. This reference to current means the A.C. component. We differentiate between the steady value of plate current and that variation in current due to the application of an A.C. potential across the grid-filament circuit by calling the former the D.C. component and the latter the A.C. component.

If we correctly interpret the action of the grid with respect to its effect upon the plate circuit, it is possible to imagine an arrangement wherein the grid filament circuit is classed as a generator developing a voltage in the plate circuit equal to the amplification constant or "mu" times the voltage applied or "mu eg." This voltage is then in series with the plate resistance of the tube so that the current is controlled by these two factors. Mind you, we are now concerned with the tube allied with A.C. voltage and current. Such a circuit would be shown as in Fig. 117. The grid filament circuit is shown as the generator and "rp" as the plate resistance.

An analysis of the circuit shown in Fig. 117 brings to light two conditions. Both voltage and current are available in the plate circuit. If we arrange to place some element into the plate

circuit it will of necessity be in series with "rp," hence will have a controlling effect upon the A.C. component of the plate current. Obviously this element cannot be a condenser because it will prohibit the application of the D.C. plate voltage to the tube. Hence two elements are possible for insertion. One is a resistance and the other is a choke. Both will permit the passage of direct current and the application of the required D.C. plate potential. These two circuits are shown in Figs. 118A and 118B, the former with a resistance in the plate circuit, other than the plate resistance of the tube, and the latter with a choke or impedance in the plate circuit in addition to the

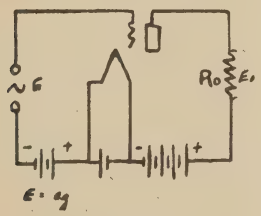


FIG. 119A

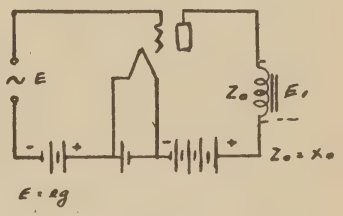


FIG. 119B

regular plate resistance. We shall designate the external resistance as the load resistance and employ the letters Ro to indicate external resistance. What has been said about chokes or windings in general was sufficient to qualify the application of the name external impedance, since the winding is possessed of that property of impedance. Following in line with what was stated about the resistance, this impedance may also be known as the load impedance imposed upon the plate circuit of the tube and is designated as Zo. An idea of the location of such an external resistance or impedance in the conventional three element vacuum tube circuit is shown in Figs. 119A and 119B. The resistance Ro can take any form, wire wound, graphite or carbon, in fact any thing which possesses the property of resistance yet will allow the flow of direct current in a steady state. The same is true of the impedance Zo. This winding may be an ordinary winding such as an air core coil. It may be the primary of a transformer or it may be a choke

of a large number of turns wound upon an iron core or upon an air core.

Let us now study the effects of such elements in the plate circuit of the vacuum tube, bearing in mind that the circuits shown in Figs. 119A and 119B are identical to the circuits shown in Figs. 118A and 118B. That resistance located between the filament and plate within the tube in Figs. 119A and 119B is that shown as "rp" in Figs. 118A and 118B. Suppose we state with the generation of a voltage "mu eg" by means of the action of the grid. Referring to circuits 118A and 118B, the alternating current in the plate circuit will be governed by the sum total of the tube plate resistance and the load resistance.

Considering the location of "rp" and Ro, one within the tube and the other external of the tube, it is obvious that the drop across "rp" is useless to us, since it takes place within the tube. It is also obvious that this loss in voltage, for it is nothing else, cannot be avoided. A certain quantity must be lost. Of course it is lost only because we cannot utilize it. However it is possible to minimize the amount lost by making Ro as great as possible, consistent with the maximum value which will allow the application of sufficient D.C. potential to the plate of the tube. This is a matter of simple division of voltages. Recognizing what was said about the phase relation of voltage and current in a circuit which is purely resistance, the determination of voltage, current and voltage drop is ordinary Ohm's Law, hence while each increase in the value of Ro will reduce the total value of "ip" in the plate circuit it will nevertheless allow for a greater voltage drop across the external load resistance.

Now, what about the voltage drop across the external resistance. What is to be done with it? The answer is simple. It is applied across the grid filament circuit of a succeeding tube. We shall not attempt at this time to consider the transfer of voltage from one tube to the other. However, let us proceed with the relation between the voltage drop across "rp" and that across Ro. The higher the voltage drop across Ro, the greater the amount of voltage actually taken out of the tube, or if we

express it in another manner, the greater the transfer of voltage from the tube to the load. If this be true, then while the action of the grid voltage fluctuation is to cause a plate current variation, this plate current variation is again employed to produce maximum voltage drop across an external resistance. It is necessary however to realize that the above condition is true irrespective of the value of Ro, but by making Ro large in comparison to "rp," the maximum amount of voltage transfer ensues between the tube and the load. When such a condition is existent, it is said that voltage amplification is being accomplished.

It is essential at this time to state, that the significance of voltage amplification is not the use of a resistance load. Instead it is that state at which time the tube is so employed by virtue of the relation between the load impedance and the tube impedance, in other words the ratio between these two impedances (the fact that the load is a resistance does not mean that it cannot be termed an impedance, since the impedance of a pure resistance is the same value as the resistance) makes possible the maximum transfer of A.C. voltage developed in the tube, because of its amplifying properties, to the load.

It is evident that such a combination of a tube operated in conjunction with a load impedance develops a new amplification constant, representing the voltage E fed into the tube and the voltage E1, developed across the load impedance as in Fig. 119A. Since the ratio between "rp" and Ro is the governing factor, it is clearly evident that while the tube actually amplifies according to its value of "mu," the full "mu" of the tube is never realized, since a certain value of voltage developed within the tube is lost across "rp." Hence the ratio between E1 and E can never be equal to "mu eg." By raising the value of Ro to a very high value it is possible to approximate the value of "mu" of the tube, so that the actual voltage taken out of the tube is equal to "mu eg."

When a resistance is located as shown in Fig. 119A, the tube is said to be working into a resistance load. An examination of the aforementioned formulae associated with the voltage transfer between the tube and the load, clearly indicates that the

plate resistance of the tube has a great deal to do with the selection of the external load resistance or impedance; that the greater the tube plate impedance, the greater must be the load impedance or resistance.

Inductive Load

Bearing in mind the required ratio with a resistive load, let us see what takes place with an inductive load, as shown in Figs. 118B and 119B. It is needless to explain at great length that the presence of the impedance (the winding constituting the choke) designated as Zo, is going to limit the A.C. component of the current in the plate circuit of the vacuum tube. This time too, we are going to strive for maximum voltage transfer in the quest for highest voltage amplification. However in this case, the load is inductive instead of resistance, and the calculation is different, because of the phase relation between the voltage and current in the plate circuit. No longer is the voltage in phase with the current across "rp" and across Zo. Hence that influence which governs the magnitude of current in the plate circuit (A.C. and NOT D.C.) the sum of "rp" + Zo. Instead it is necessary to determine the total impedance of the plate circuit, which value involves both "rp" and Zo.

Let us for the sake of argument assume that the winding designated as Zo is a pure reactance that is a coil with either no resistance (which of course is impossible in actual practice) or of such low resistance that it is negligible in comparison with the reactance Xo, in which case Zo = Xo. Then the total hindrance to the flow of current in the plate circuit shall be the total impedance of "rp" and Xo.

Before proceeding we must consider another item. We stated during the discussion on reactance and impedance allied with inductances, that the reactance of an inductance or inductive reactance, varied with frequency. Thus the value of Xo which is really X_L in ohms, is dependent upon the frequency of the input voltage E. The higher this frequency, the higher the value of Xo. On the other hand, the value of "rp" is inde-

pendent of frequency for all practical purposes, so in contrast to a resistive load, we now find a situation where a constant impedance source is connected to a variable impedance. Since the desired action is that of maximum voltage transfer between the tube and the load and since such condition depends upon the impedance value of the load, and since the percentage of voltage transfer increases when the load impedance is increased, we should select the lowest frequency for the determination of the voltage transfer between "rp" and Zo, because the action will improve as the frequency of E is raised, assuming that such is actually the case in practice. As a matter of fact it is customary in practice to consider the value of the load impedance at the lowest frequency to be encountered in practice. Hence we shall for illustration assume that the frequency of E is 40 cycles. Such items were of no interest in the case of the resistance load, since the value of resistance for a certain resistance, free from capacity and inductive effects, remains constant regardless of frequency.

Reference made before about modern inductive units employed in vacuum tube plate circuits pertained to the units which employ alloy cores, so that the ratio between the reactance and the resistance is so great that the presence of the resistance would have very little effect upon the final value of impedance. The only exception to this rule is the loudspeaker known as the electromagnetic cone, which shall be described later.

Tube circuit arrangements so as to secure voltage amplification are quite numerous in sound motion picture systems. As a matter of fact all the tubes employed in an amplifier with the exception of the tubes which feed the speakers and those used to convert A.C. into D.C. are arranged to function as voltage amplifiers. This is necessary because the vacuum tube is a voltage operated device and in order to deliver the maximum amount of electrical energy to operate the loud speakers, the maximum value of signal voltage must be applied across the grid-filament circuit of those tubes which supply the power to the loud speaker reproducers.

POWER AMPLIFICATION

We know that the application of an alternating voltage across the grid filament circuit of a vacuum tube will produce in the plate circuit an alternating potential and an alternating current. Also that the process of amplification within the tube results in amplification of voltage. It is possible however to employ the same vacuum tube as a means of amplifying power, that is to convert the voltage fed into the grid circuit into power in the output circuit. Such operation is very desirable in an amplifying system, because many of the devices employed to convert electrical energy into sound via mechanical motion, require power for their operation rather than voltage. The interpretation of power in this case means nothing more than a large value of current in the plate circuit.

Reference to what was said about voltage amplification shows that the magnitude of A.C. current in the plate circuit of a tube used as a voltage amplifier is very little. However when the tube is used as a power amplifier, it is necessary to arrange that the current in the plate circuit be maximum. This suggests that whatever device is connected into the plate circuit be of low resistance or low impedance. This is quite true, but it is also necessary to remember that when current and voltage are present in the circuit, a certain amount of power is dissipated across the tube plate impedance as well as across the external resistance.

Perhaps you wonder at this stage, why it is impossible to utilize most of the power available across the external resistance by making the resistance equal to several times the tube impedance. The reason is founded on the fact that certain devices, particularly loud speakers, require the maximum current for operation and as such make necessary the relation shown. This gives rise to the idea that if Ro is less than "rp,"

the current through Ro will be greater. That is true, but it introduces another factor, the operating characteristic of vacuum tubes. Generally speaking, the impedance in the plate circuit of a vacuum tube must at all times be greater than the tube plate impedance. If it is less, distortion will be the result, a condition which must be avoided in amplification of speech and music. Therefore the optimum condition for maximum power transfer is a state of equal impedances. This is true in all electrical circuits. With respect to tube operation however, it will be found that, that part of the amplifying system employed to operate as a power amplifier, converting voltage input into power in order to actuate a power operated device like a loud speaker, entails an impedance relation where the load impedance is equal to twice the tube plate impedance. The reason for this is that such a condition minimizes distortion, yet enables the transfer of maximum power. In other words maximum undistorted power is transferred from the tube to the load when the load impedance is equal to twice the tube impedance.

We stated that if the voltage input to a voltage amplifier is doubled, the voltage output or the voltage developed across a resistance in the plate circuit of that tube will be doubled. In the power amplifier however, the relation is different. If the input voltage is doubled, the output power is increased fourfold. That is, the power output varies as the square of the input voltage. This explains why certain power tubes do not afford the required power output in audio amplifying systems. The actual reason is that the required voltage input, as stipulated by the tube manufacturer in order that the rated power output be secured, is not applied.

We have observed that a certain voltage and a certain current are present across a resistance located in the plate circuit of an amplifying tube. The magnitude of power across this resistance or impedance, is a matter of the exact value of resistance or impedance used as the load. Hence it is obvious that the difference between power amplification and voltage amplification is nothing more than how the tube is used, with the paramount influence being the character of the load. It is

also evident that a high Mu tube with a high value of plate impedance is unsatisfactory for use as a power amplifier, since the current in the plate circuit is very small. Another important point in connection with the use of a high "mu" tube as a power amplifier is that the output power depends upon the input voltage and since the maximum power output is required, the maximum voltage must be applied. This is impossible with a high "mu" tube, because its characteristics are such that the input voltage is limited because of the low grid bias. Hence the high "mu" tube is not suited for use as a power amplifier. Generally speaking power amplifier tubes are designed to possess a low "mu" and a low value of plate resistance. The low "mu" enables the application of a high grid bias, hence a high signal voltage and the low plate resistance means the greatest current change in the plate circuit. This is the equivalent of saying that power tubes have high values of mutual conductance.

Unfortunately however, the behavior of a vacuum tube is such that best operating condition is not secured with a low external impedance. A low external impedance shortens the length of the straight portion of the characteristic curve and distortion is present when a loud signal is passed through the amplifier. This distortion takes the rôle of harmonics which were not present in the input but which are introduced by the action of the tube and are present in the output. These harmonics change the timbre of the speech or music so that it is not a reproduction of the original. As a point of information, a small amount of harmonic distortion is allowed in an amplifier classed as distortionless, but the extent of the distortion is so small, that is, the intensity of the even harmonics is so low, that it passes unnoticed by the listener Hence it is impossible to employ an arrangement wherein the maximum power output is secured.

An increase in the value of the load impedance minimizes distortion, but it reduces the power output. Hence it is necessary to strike a compromise of the minimum amount of distortion consistent with maximum output. This condition is secured by making Zo or Ro numerically equal to 2rp.

Limiting Factors

The vacuum tubes employed in an audio amplifier are arranged to function in a definite manner. All tubes with the exception of the output tubes or those tubes which supply energy to the loudspeaker by means of some form of coupling, are employed as voltage amplifiers in order that the maximum voltage be applied across the grid-filament circuit of the output tube and thus produce the maximum value of output power. It is however necessary to remember that all items possess certain definite operating limitations and the three element tube is no different in this respect. The value of grid bias not only provides the operating axis for the input signal voltage, but definitely limits the value of the input voltage. Further if the plate voltage is increased, the value of the input signal voltage is increased. In addition remembering that the increase in plate voltage reduces the tube plate impedance, it stands to reason that the current fluctuation will be greater for any one input signal, hence the apparent amplification available with the tube is increased.

Considering each item as a whole, it is impossible to increase signal input by increasing the grid bias, because the bias required for a tube is a function of the other operating potentials and the tube structure. Too much bias is as bad as insufficient bias, distortion is the result in both cases. Increasing the signal voltage without correct tube operating potentials which will adapt the tube for the contemplated input voltage or grid swing is also a prolific source of distortion. At this stage, one would ask "Why not boost the plate and grid potentials?" The reasons are quite simple. In the first place, the electronic emission from the filament definitely limits the plate potential. While it is true that the maximum values recommended in tube literature are not the absolute maximum, it is dangerous to increase the plate voltage beyond the stipulated value because the tube elements and the spacing between the elements may not be sufficient to withstand the difference of potential created between the plate and filament, with consequent breakdown.

RCA ICONOSCOPE

This consists of an electron gun and photosensitive mosaic enclosed in a highly evacuated glass envelope. The arrangement of these elements is shown in Fig. 128C.

The electron gun produces a narrow pencil of cathode rays which serves, as a commutator to the tiny photocells on the mosaic. The gun is in reality a form of electron projector which concentrates the electrons from the cathode onto the mosaic in a very small spot. The electron optical system consists of two electron lenses which are formed by the cylindrically symmetrical electrostatic fields between the elements of the gun. Fig. 128D shows diagrammatically the arrangement of this gun, together with the equipotentials of the electrostatic fields making up the electron lenses. Below this diagram is the approximate optical analogue. Details of the gun construction are as follows: The cathode is indirectly heated with its emitting area at the tip of the cathode cylinder. It is mounted so that the emitting area is a few thousandths of an inch in front of an aperture in the control grid. A long cylinder with three defining apertures whose axis coincides with that of the cathode cylinder and control grid serves to give the electrons their initial acceleration and is known as the first anode. A second cylinder coaxial with the first anode and of somewhat greater diameter serves as second anode and gives the electrons their final velocity. The second anode is in general formed

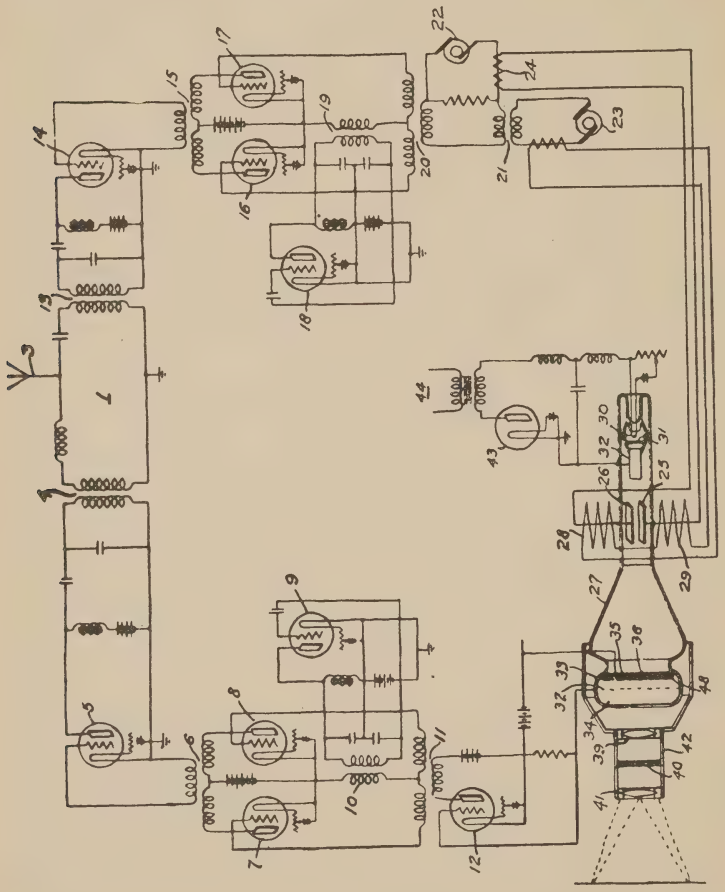
by metalizing the neck of the Iconoscope bulb, as shown in Fig. 128C. The gun used in the Iconoscope is designed so that it will concentrate a beam current of from one-half to one microampere into a spot about five mils in diameter. Under ordinary operating conditions, a potential of about a thousand volts is applied between the cathode and second anode and the voltage of the first anode adjusted until minimum spot size is obtained. The exact value of the beam current to be used will, of course, depend upon the type of picture to be transmitted and the exact conditions of operation.

The beam from the gun is made to scan the mosaic in a series of parallel horizontal lines repeated at thirty cycles per second. This is accomplished by two sets of magnetic deflecting coils arranged in a suitable yoke and slipped over the neck of the Iconoscope. These sets of coils are driven by two special vacuum tube generators supplying deflecting currents described later.

The element which characterizes the Iconoscope is the mosaic. It consists of a vast number of photo-sensitive globules or minute particles mounted on a thin mica sheet in such a way that they are insulated from one another. The back of this sheet is coated with a conducting metallic film which serves as a signal plate and is connected to the input of the picture amplifier.

The appearance of the mosaic is shown in Figure 128D. Such a mosaic may be formed in a number of ways. For the standard type of mosaic the silver globules are formed by reducing (releasing the oxygen, leaving pure metal) particles of silver oxide dusted over the mica. Under proper heat treatment the silver globules reduced from the oxide will not merge with one another but will form individual droplets. These droplets are sensitized after the mosaic has been mounted in the glass envelope and the envelope evacuated The sensitization is similar to that used in the ordinary cesium photocell; that is, the silver is oxidized, exposed to cesium vapor, and then heat treated. The result is that the photo-electric response of these glo-

bules is about the same as that of a high vacuum cesium photo-electric cell, both in sensitivity and color response.



Tests indicate that the Iconoscope with a quartz window is sensitive from well into the infra-red portion of the light spectrum through the visible, and into the ultra-violet lighter portion.

The mica on which the silver droplets are mounted serves to insulate them from one another and further

is made thin enough so that the capacity between each globule and the metallic signal plate will be reasonably large. The uniformity of cleavage sheets of mica, together with their excellent insulating properties, low dielectric hysteresis and low loss make them very suitable for this purpose.

The mosaic is mounted in the tube with the silver beads facing the beam. In order that the optical image may be focused on its front surface, it is placed in the tube in such a way that a normal to its face makes an angle of 30 degrees to the axis of the electron gun.

In essence, the Iconoscope may be thought of as a plain mosaic made up of a great number of individual photocells, all connected by capacity to the common signal plate and commutated by the scanning beam. The fundamental cycle of operation is as follows:

Every silver globule making up the mosaic is photosensitized so that when a light image is projected on the latter the light causes electrons of a number proportional to the light brilliance to be emitted from each illuminated minute size photosensitive area. The resulting loss of electrons leaves each photosensitive area at a positive potential without respect to its initial condition which potential is then proportional to the number of electrons which have been released and conducted away so that the mosaic tends to go positive at a rate proportional to the light falling on it.

As the electron beam scans the mosaic, it passes over each element in regular order, releasing the charge it has acquired and driving it to equilibrium by restoring an equal number of electrons to the globules. Due to the fact that each element is coupled by capacity to the signal plate, the sudden change of charge of the elements will induce a change in charge on the signal plate and result in a current pulse in the signal lead connected to the amplifier.

The magnitude of these pulses will be proportional to the intensity of the light falling on the scanned element. Thus the signal output from the Iconoscope will consist of a chain of electric current pulses corresponding to the light distribution over the mosaic. This

chain can be resynthesized or interpreted at the receiver into a reproduction of the original image, as will be described later.

To clarify this cycle the equivalent circuit representation of a single element is shown in Fig. 128G. The beam is represented by the switch and the series register *R*. This switch may be considered as being open except at such times as the beam is actually on the element. When the scanning beam moves off the

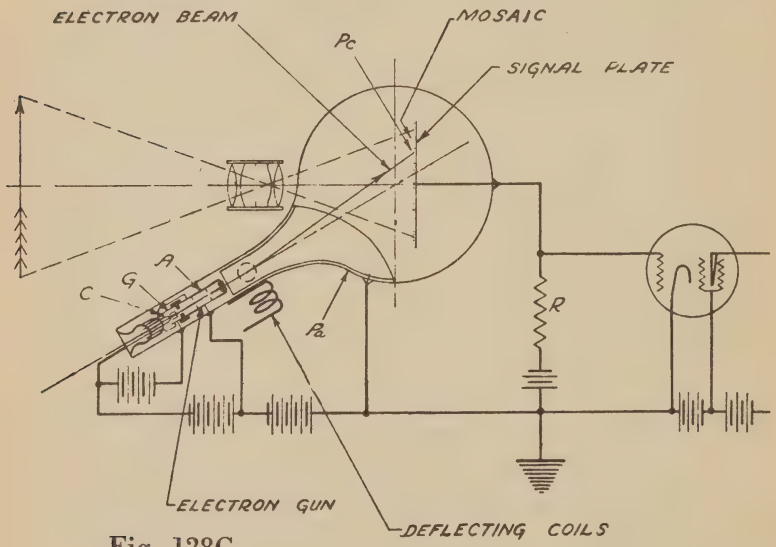


Fig. 128C.

element in its regular course, the photo-emission from the element starts to charge the condenser *C*, the rate of accumulating charge being proportional to the illumination on the element.

In the next scanning cycle, one thirtieth of a second later, the beam again sweeps over the element, closing the switch and discharging the element. During this discharging cycle the entire charge accumulated during the time the beam was not on the element must now flow through the input resistor *R1* generating a

voltage which is applied to the input of the picture amplifier. It can thus be seen that fluctuating current is sent to the picture amplifier from a huge number of similar circuits which is an interpretation of the distribution of light over the entire scene.

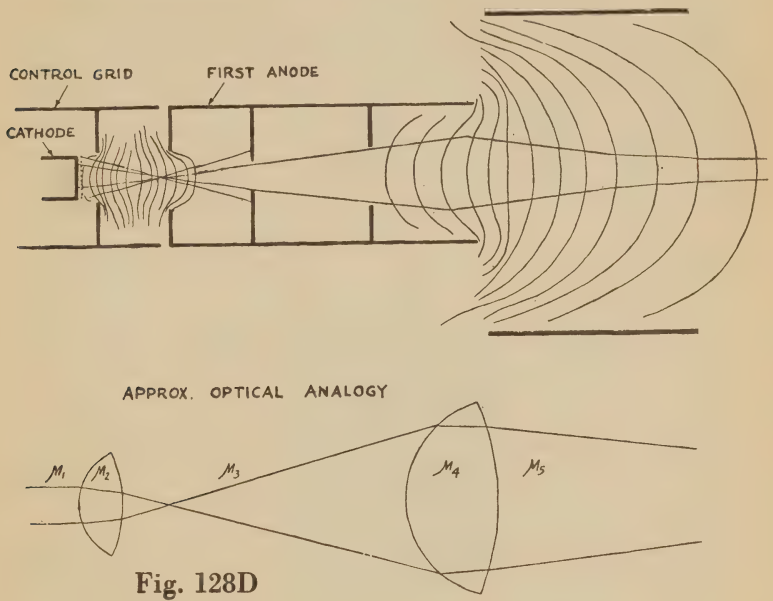


Fig. 128D

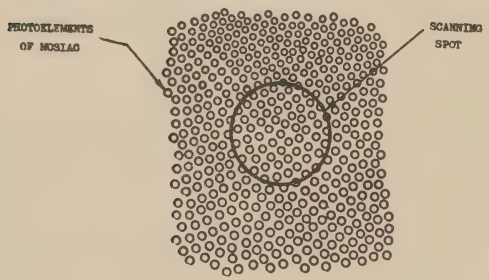
In designing the mosaic, it is evident that the time constant of the circuit discharging the condenser *C* must be small enough to allow it to fully discharge during the time the beam is on the element.

ICONOSCOPE PICK-UP TUBE

The Iconoscope pick-up tube employs the storage principle in that the electrons are stored after they have been released from the mosaic globules until the mosaic is scanned by the electron beam. It is interesting to note that the voltage supplied is greater than the equivalent voltage from a non-storage system by the ratio of the number of picture elements: You will recall that for present day pictures this was about 250,-

000 times. This is quite an important factor in the amount of amplification required.

In order to give a better pictorial idea of the conditions of the surface of the mosaic, Fig. 128H is shown. It represents the appearance of the charged image on the mosaic if it were visible to the eye. The region just behind the scanning beam, the top of the mosaic, is in equilibrium potential since the emitted electrons have been restored to the globules by the beam, and therefore shows no visible image. It may be noted that the portion of the image just ahead of the scanning beam is of greatest intensity since it has had the longest time for charging.



The picture just drawn of the operation of the Iconoscope is very much simplified. A number of factors complicate this seemingly straightforward .cycle. Among the most important of these complicating factors are the potential distribution over the mosaic and the redistribution of secondary electrons emitted from the elements under bombardment. Due to the fact that the potential or voltage between globules on the mosaic and the second anode, which collects the emitted secondary electrons, varies over the mosaic and due to the fact that some of the electrons emitted return to other portions of the mosaic instead of reaching the sec-

ond anode, there is a loss of efficiency.

Taking into account the various factors tending to reduce the output of the Iconoscope, it is found that the net efficiency of conversion is in the neighborhood of 5 to 10 per cent. In other words, the signal output is about 1-20th that which would be expected on the basis of the light flux reaching the mosaic, the saturated photo-emission of the photo-electric elements, and the assumption that the entire photo-current is stored by the mosaic. The efficiency of conversion is not constant but depends on the amount of light used. The efficiency is a maximum at low light and decreases as the light is increased.

It is interesting to note that the Iconoscope, taking into account its inefficiency and imperfections, is able to operate at one-tenth the light required by a perfect non-storage system, which includes an electron multiplier.

The resolution, that is, the capacity to show small details, especially to show as separate two points of light close together, of an Iconoscope may be limited either by the size of the photo-electric elements or by the size of the scanning beam. The size of the silver globules in the Iconoscope is many times smaller than a picture element (5 mils) so that many hundreds of them act together under the scanning spot. The resolution is limited, therefore, by the spot size.

SENSITIVITY OF ICONOSCOPE

The sensitivity of the Iconoscope decreases with illumination. This is not wholly disadvantageous in that it permits the transmission of a wider range of contrast over a given electrical system than would otherwise be possible. In a sense, this is similar to the compressor-expander systems used in sound recording. The Iconoscope is an extremely sensitive and stable device for obtaining television transmission. Excellent and consistent results are obtained under widely varying conditions of operation. The practical lower limit to light which can be used to transmit a picture is set by the "noise" in the picture amplifier.

Measurements have been made to determine the illumination necessary for satisfactory operation. With an F-2.7 lens to focus the image on the mosaic, an average surface brilliancy of from 30 to 50 candles per square foot on the object view gives completely satisfactory transmission. A recognizable image can be obtained from a good Iconoscope with 8 candles per square foot using a F-16 lens; that is, with 1-150th the illumination mentioned above.

RCA KINESCOPE

The cathode ray tube used in the RCA television receiving system is known as the "kinescope." It is capable of producing a picture image comparable with that focused on the pick-up tube at the transmitter.

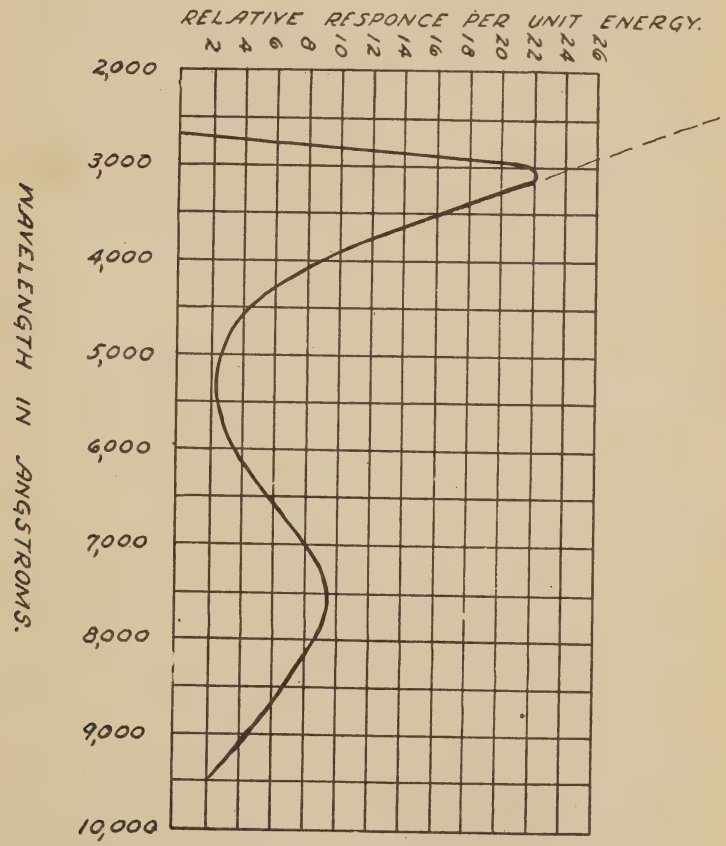
The kinescope, Fig. 128J, consisting essentially of a glass tube with a cathode ray electron gun similar to that in the iconoscope, except that it is made to handle larger currents and to operate at higher voltages. Furthermore, since the picture is reproduced by modulating or controlling the beam current, the control grid is a much more critical item. A fluorescent screen is placed at the large end of the tube.

A diagram showing the construction of the kinescope is shown in Fig. 128K. The electron gun is made up of a cathode C, with its emitting area coated with barium and strontium oxides. The cathode in this case operates from alternating current. The control grid, *G*, is placed around the tip of the cathode. An aperture, *O*, is located in the grid directly in front of the cathode so that the electron beam may be efficiently directed toward the first anode.

Since the grid is furnished with a negative current the electrons are repelled and forced toward the aperture. The first anode, *A1*, with several apertures which guide the electron beam toward the fluorescent screen is placed in front of the grid. This first anode has a high positive voltage to accelerate the beam. Since it is desirable that the electron beam be sharply focused at the fluorescent screen to an area equivalent to the minute area scanned by the pick-up tube, further means of focusing is provided. The electrons which

would naturally diverge are forced to take a path of travel near the axis of the tube by the lines of force set up. Accurate focusing is thus accomplished.

The inner surface of the tube is coated with a thin



layer of colloidal graphite which acts as a second anode, *A2*. This anode again accelerates the beam.

The fluorescent screen is made by coating the flat portion of the bulb with a synthetic zinc orthosilicate, very similar to the natural Willemite. The synthetic

material gives off a green colored light and has high luminous efficiency. In addition to its high luminous efficiency, this material does not burn or disintegrate under electron bombardment. The phosphorescent properties of a fluorescent material are an important consideration.

An ideal substance for television work should emit a constant amount of light for one entire picture frame and drop to zero at the end of this period. If the phosphorescent time is too long, the moving portions of a picture will leave a "trail." For example, the path of a moving ball will be marked with a comet-like tail. On the other hand, if the delay time is too short, flicker becomes noticeable. This would be caused by the period of complete darkness between pictures.

Since the pictures are reproduced, as well as picked-up, by scanning from top to bottom, it is desirable to have the screen hold the light long enough until the entire picture has been scanned. With interlaced scanning where two sets of scanning are really required for a complete picture, since only alternate lines are successively scanned, this "delay" characteristic is also desirable. Thus the phosphorescent properties of the fluorescent screen are important.

CONTROLLING THE GRID

In order to reproduce a picture image on the fluorescent screen equivalent to that focused on the pick-up tube, the intensity of the spot of light upon the screen must be varied in a proportion to the original. This is accomplished by controlling the grid. The picture or video signals received are fed to the control grid of the kinescope. These varying currents tend to control the electron beam intensity through the grid just as is done in a vacuum tube of the triode type. Thus, the illumination on the screen is a direct proportion of the incoming video signal which relates it directly to the illumination intensities of the orginal image at the transmitter.

It was found that the second anode also acted to carry off the secondary emission of the fluorescent screen. The electron bombardment of the screen in a

short time would produce enough of a "negative charge" to repel all of the electrons unless these excess electrons were disposed of. Thus another cathode ray tube is employed to reproduce the televised image comparable to the pick-up tube in the transmitter. In this case the electron beam produces a reproduced image on a fluorescent screen instead of scanning a photosensitive mosaic. The method of producing and deflecting the electron beam is, however, quite similar in both the iconoscope and the kinescope.

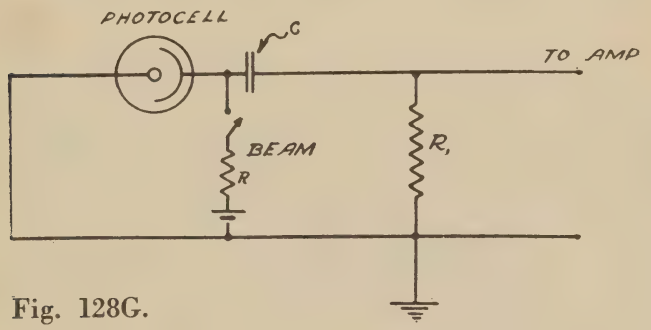


Fig. 128G.

The kinescope has also been used for large screen television images by the use of an optical system which magnifies and projects the image on the fluorescent screen onto a large screen. The limitation of the intensity of the lightemitted by the kinescope is an important factor in this method of enlarging the image.

FARNSWORTH'S OSCILLIGHT

The cathode ray receiving tube used in the Farnsworth system is called the "oscillight." Essentially this vacuum tube consists of an electron gun, a fluorescent screen, together with a focusing and deflecting system.

The electron gun in the oscillight, Fig. 128M, consists of the usual type of heater type cathode. In this case it consists of a cylindrical piece of metal with a concave end facing the fluorescent screen which is coated with the usual barium and strontium oxides. A grid, cylindrical in shape but of somewhat greater di-

ameter, is placed over the cathode. One end of the grid is closed but a small aperture is placed in this closed end. Thus the electrostatic field of the anode may pass to the cathode.

The anode is placed directly in front of the grid. It has a nozzlelike end facing the grid to stimulate a point of charge from which the lines of force originate. This permits accurate focusing of the electron beam.

Some means had to be provided to remove the charge built up at the screen end of the tube as a result of secondary electron emission from the screen.

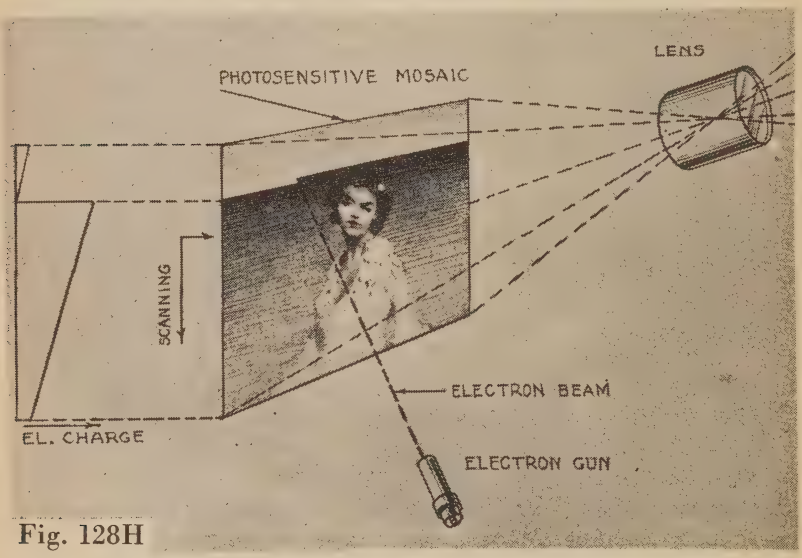


Fig. 128H

This was accomplished by providing a thin film of nickel on the inner wall of the tube which is connected to the anode. The secondary emissions are then drawn from the screen by this metallic layer.

A short focusing coil is wrapped around the neck of the glass tube. By energizing this coil accurate focusing is possible and, once set, further adjustment is not required.

Deflecting coils are required in order to horizon-

tally and vertically deflect the electron beam in the sameway as is done in the pick-up tube. In the oscillight an air core coil placed as close to the tube as possible, inside the focusing coil, is used for the horizontal deflection. This type of coil is most sensitive for reasonably high frequencies. An iron-core electromagnet, however, is used for vertical deflection. The principal advantage of this is that its effect can be restricted to a very small area and thus it minimizes interference with other circuits and coils. For the low frequencies involved in the vertical deflection the ferromagnetic type is preferable.

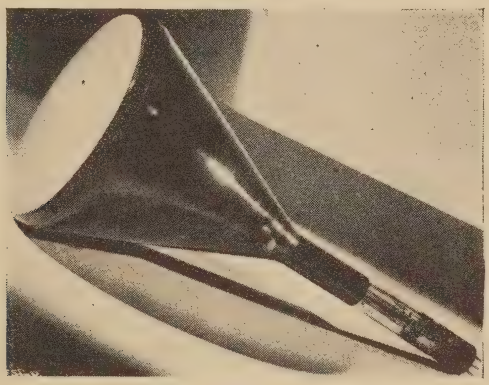


Fig. 128J, *The Kinescope*

The proximity of deflecting coils which operate simultaneously presents several problems. The coils are, therefore, placed as far apart as practical. The horizontal coils deflect the beam first in a simple linear deflection. Specially designed pole pieces are required for the vertical deflecting coil for uniform action.

The cathode is heated by either a.c. or d.c. and it then emits electrons. A "mist" of electrons traveling in many directions and at a great variety of speeds is thus produced around the cathode. By placing an anode nearby and energizing it with respect to the cathode, it is possible to form the electrons into a stream flowing toward the anode, and by placing a hole in the

anode the stream may be directed. The anode also accelerates the electron flow. If the current heating the cathode is uniform. A grid is placed between the cathode and anode. The picture signal received is conveyed to the grid. The grid controls the electron stream in direct proportion to the current imposed on it. The result of this control is to increase or decrease the effect of the stream on the fluorescent screen by increasing or decreasing the concentration of the electrons in the stream. As the current to the grid increases, the spot on the screen grows brighter and vice versa.

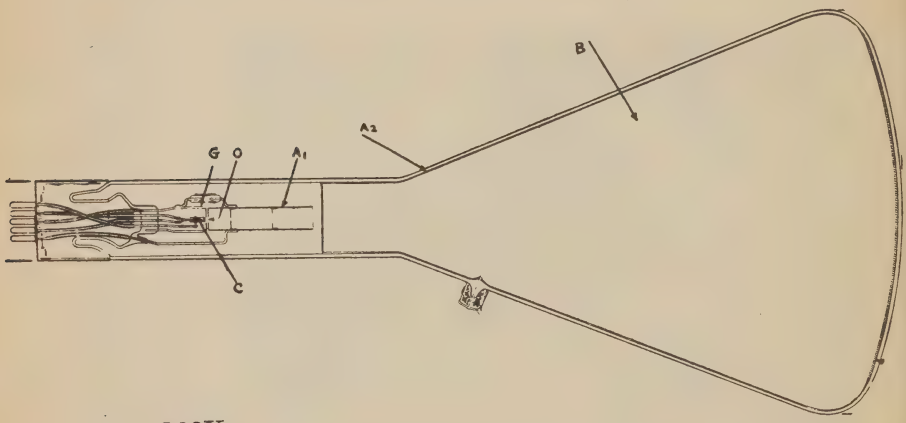


Fig. 128K. *Schematic diagram of the kinescope*

The fluorescent screen is placed on the inner surface of the end of the glass tube. The chief advantage of the fluorescent screen over other possible methods of reproducing light is its sensitivity to very short periods of excitation. It has the property of absorbing electrical energy and emitting light. Thus the screen is made sufficiently thin so that most of the light emitted passes outside the tube.

Synthetic zinc silicate closely resembling the composition of the mineral Willemite is used for the fluorescent screen. This material lends itself particularly to this use since it does not deteriorate or chemically decompose as a result of electronic bombardment, and it

also emits a light of bright green which lies in the color range to which the eye is most sensitive. The intensity of illumination is, of course, directly proportional to the intensity of the electron beam. Further experiments have been completed to perfect a material for the fluorescent screen which will emit a white light.

In order then to translate the signal transmitted

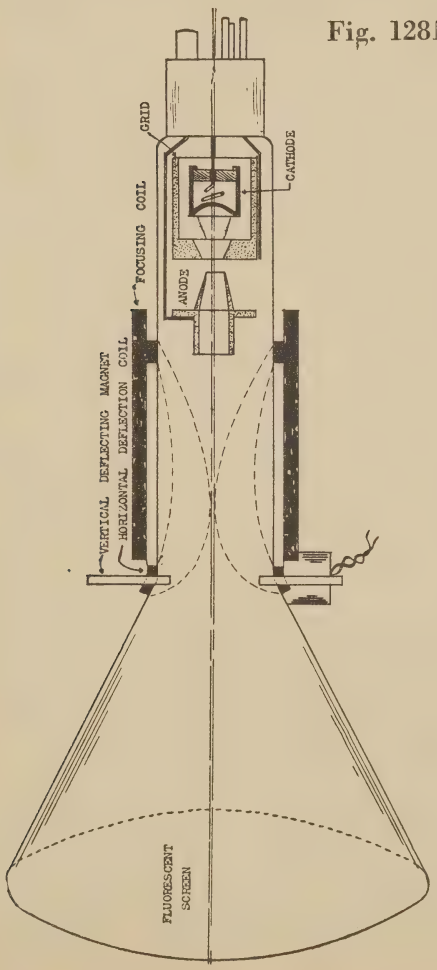


Fig. 128M, *Diagram of the oscillight*

into a picture equivalent to that originally focused on the pick-up tube, the electron beam, varying in direct proportion to the transmitted signal, is directed at the fluorescent screen. The light emitted by the screen is proportional to the intensity of the beam and thus to the transmitted signal. All that is then necessary is to deflect the beam both horizontally and vertically just as was done in the pick-up tube. It will then trace on the screen the original picture which can be viewed from the outside.

To control the average brilliancy of the picture emitted by the screen it is necessary to regulate the grid bias or potential. In focusing the beam it is desirable that the area on the screen of the beam is equivalent to the area of the minute area scanned in the pick-up tube.

SCOPHONY SKIATRON

The "skiatron," another device for reproducing television images, is a development of Scophony. In some respects it is similar to the light valve of RCA. The skiatron makes use of the full storage principle.

As shown in Fig. 128N, the skiatron consists of a cathode-ray tube device in which a crystalline screen is exposed to the modulated and deflected cathode-ray beam. The screen material exhibits the property of "electron opacity," that is, it can be rendered opaque by being scanned by a cathode-ray beam. By subjecting the screen to a suitable electric field and temperature it is possible to cause the opacity to remain constant for substantially the whole frame period and to then disappear quickly when the beam returns to produce the opacity for the following frame.

The crystal screen consists of a material such as sylvine, or rock salt, in micro-crystalline form. The effect of the impact of the cathode-ray on to the crystal is the formation of an opaque deposit which travels in the direction of the electric field through the lattice toward the anode and ultimately disappears there. The total time of travel of the deposit through the

crystal, or in other words the persistence of constant opacity at one element, depends upon the strength of the electric field and temperature and certain crystal constants.

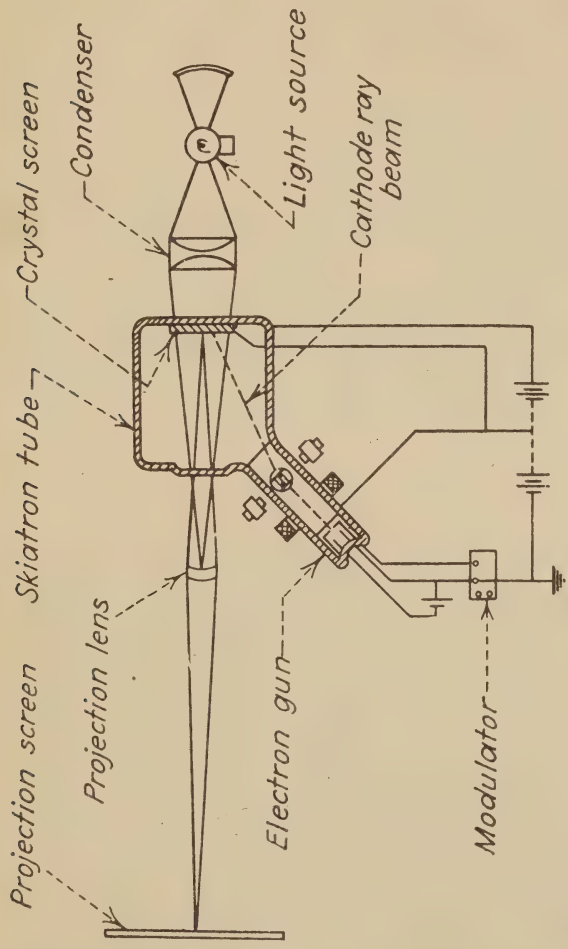
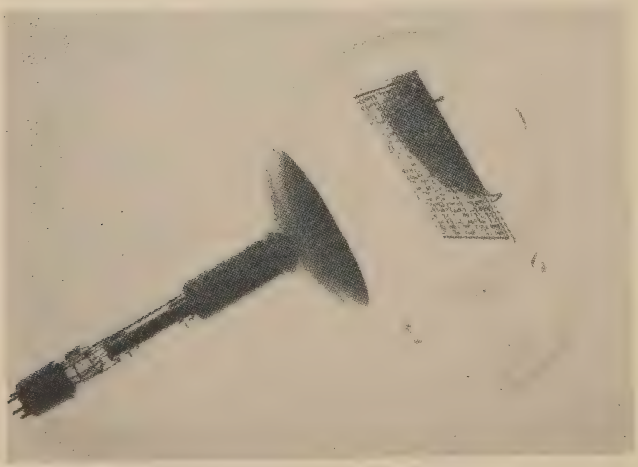


Fig. 128N. *Schematic diagram of the Skiatron and its associated circuits*

With a sylvine crystal one millimeter thick and a potential of 600 volts at its ends, the deposit would move through the crystal, or remain in visible exist-

ence within 1-30 second, equal to the frame period of present television standards. At the same time that the deposit at a certain element enters the anode, thus disappearing, the scanning cathode-ray beam returns to this particular element and creates a new deposit of a value belonging to the following frame, at the cathode side of the crystal. This deposit then starts on its travel through the crystal toward the anode which it reaches at the end of this frame period. Thus it is possible to retain the elemental intensity values constant over the entire frame period, and change them at the end of this period to the value corresponding to the following frame. In this way is full storage television reception achieved.

The skiatron utilizes a projected light source as shown in Fig. 128N. It can be well used for large screen television images where the principal limitation will be the size light source used and the optical system including the crystal screen.



-Photograph of Monoscope.

THE MONOSCOPE

"Monoscope" is the name which has been given to a developmental type of tube designed to produce a video signal of a test picture or pattern enclosed in the tube. Since the picture must be enclosed in the tube, the Monoscope is not suitable for developing a video signal which represents action. However, a signal of excellent fidelity can be obtained for a "still" picture which contains half-tones or consists only of lines.

Two general types of tubes which can be used for this purpose are: first, the type which utilizes the primary current of the scanning beam to produce the video signal, and second, the type which makes use of the secondary-emission current obtained when a suitable material is scanned with an electron beam.

Briefly, the first type of tube has a signal plate of some desired configuration cut from a conducting surface. When the plate is scanned, a signal current is obtained each time the beam strikes the plate. As a result, this video signal will produce a picture of the plate when applied to a suitable reproducer.

The second class of tube can be made in a number of workable combinations. In general, two materials having different secondary-emission ratios are used to make the signal plate. As this plate is scanned, one magnitude of secondary-emission current is obtained from one material and another magnitude is obtained from the second. The difference in the magnitudes of these secondary-emission currents determines the amount of video current. Therefore, if two materials

which have a numerical difference in secondary-emission ratios greater than one are used, it is possible to develop more video current than would be possible if only the primary current of the beam were utilized. Because of the attractiveness of this arrangement, a number of combinations of two materials having different secondary-emission ratios was investigated. A technique of preparing signal plates was developed which permits the accurate reproduction of all types of subject matter. The structure of a tube employing this principle will now be described.

MONOSCOPE STRUCTURE

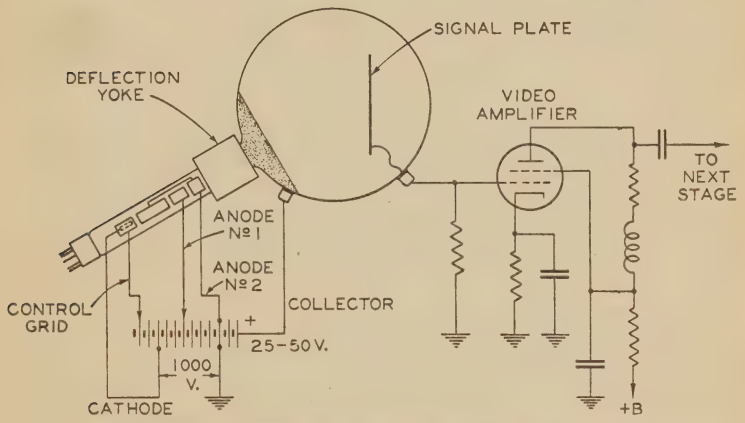
The tube consists of an electron gun, a signal plate, and a collector enclosed in a highly evacuated envelope. The electron beam is scanned over the signal plate by an electromagnetic deflection system.

The electron gun which supplies the scanning beam must be of high quality if the best video signal is to be obtained. The electron beam should be very small when it strikes the signal plate if good resolution is desired. The beam current should be reasonably high because the video current varies directly with beam current. However, the size of the beam should not be sacrificed to obtain high beam currents. The electron gun developed for Iconoscopes, provides a small beam with adequate current, and therefore, was readily adapted to the Monoscope. The final anode of this gun operates at 1000 volts, and a very small beam can be obtained for currents of several micro-amperes. The use of this gun proves to be an advantage in test work when it is desired to use a Monoscope in an Iconoscope camera.

The signal plate is made from aluminum foil and carbon. The surface of the aluminum has a natural coating of aluminum oxide which has a reasonably high secondary-emission ratio while the carbon has a relatively low ratio. It was found that aluminum foil developed for advertising and packing purposes as well as special inks developed for printing on metal foils were satisfactory materials for signal plates. As a result the advantages and flexibility of commercial printing processes can be utilized. The desired picture or

pattern is printed on aluminum foil with a black-foil ink. The only other processing necessary before sealing the signal plate in the tube is to fire it in hydrogen. This process removes the volatile matter from the ink and thus leaves it practically pure carbon.

Subject matter for reproduction on a signal plate can be divided into two classes: black and white, and half-tones. Cartoons are a good example of the first, while snapshots, which contain tones between black and white, illustrate the half-tone group. Photo-engravings



Schematic diagram to show Monoscope connections.

are made of the subject matter for printing the signal plates. The black-and-white material is treated as a line-cut, but the half-tone material must be broken into a number of dots of various sizes depending on the half-tone value. This is done when the photo-engraving is made by photographing the material through a suitable screen. A screen is used which will break the picture into more elements than are used in the television scanning system for which the tube is designed. As a result, this technique of obtaining half-tones does not limit the resolution of the television system and the half-tone effect is reproduced just as in a newspaper photograph.

In order to give the picture the correct polarity on the Kinescope, i.e., so that white corresponds to white in the original, it is necessary to make the signal plate in a definite manner, depending on the number of stages in the video amplifier. If the video amplifier has an odd number of stages (as is normal between Iconoscope and Kinescope) the picture on the signal plate of the Monoscope should have blacks and whites reversed, but should not have printed matter reversed. The reversal of blacks and whites is necessary because the aluminum oxide, although white in appearance, has a higher secondary-emission ratio than the carbon, and, therefore, produces a signal which corresponds to black.

The secondary-emission current from the signal plate is collected by a conductive coating on the bulb wall. This coating is operated at a potential positive with respect to the signal plate, which is operated at the same potential as the final anode of the electron gun.

OPERATION OF THE MONOSCOPE

The electrical operation of the Monoscope is very similar to that of the Iconoscope except that a collecting voltage is required for the secondary-emission from the signal plate. However, no optical system is required because the test picture or pattern is enclosed in the tube. For convenience, the second anode is operated at ground potential. The first stage of the video amplifier may be operated with self-bias or fixed bias. In the latter case the bias adds to the collecting voltage, but the value of the combined voltage is not critical for potentials above 20 or 30 volts.

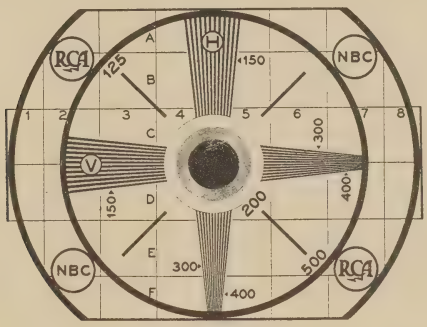
The video amplifier must be of high quality to amplify faithfully the video signal. If the signal is to be used for test work, the frequency band of the amplifier should be broader than the circuits under test so that limiting conditions will not be confused.

USES OF THE MONOSCOPE

The Monoscope may be used for a variety of pur-

poses. In commercial applications, frequently repeated announcements and advertisements could be taken from a Monoscope. Fixed backgrounds for studio work could be obtained—the final signal being a suitable combination of video signal from an Iconoscope for action and from a Monoscope for background.

However, the biggest field for the Monoscope is in television testing. The same video signal can be obtained from day to day, and the quality is not affected by such variables as poor optical focus, dark spot, and amplifier noise. The Monoscope, therefore, is an important device for checking performance of Kinescopes, receivers, and studio systems.

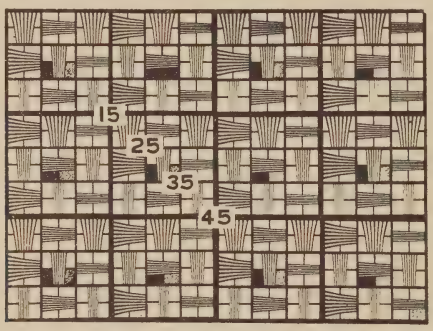


Test pattern for checking resolution.

KINESCOPE TESTS

The television-tube manufacturer is concerned with how well his product will perform when reproducing video signals. Short-cut tests have been tried, but give poor correlation with the results obtained when an actual picture is reproduced. However, the quality of the latter is difficult to reduce to a quanitative basis unless the test picture or pattern has a specific character which can be accurately converted into a reliable video signal. The Monoscope is admirably suited for this purpose.

Simple tests insure the quality of the video signal used for rating the Kinescope. If the scanning on the Monoscope is reduced and that on the Kinescope is maintained at normal, an enlargement of the scanned portion of the signal plate will be seen on the Kinescope. This enlargement removes the possible limitation of Kinescope resolution. Also, the reduced scanning lowers the frequency band of the video signal so that the video amplifier does not limit the resolution. Under these scanning conditions, the focus of the electron gun in the Monoscope can be accurately set to give maximum resolution. The electron gun used in the



Test pattern for checking all parts of scanning pattern.

Monoscope will give a resolution of 500 to 600 lines without difficutly; therefore, it more than fulfils the requirements of the present system of 441 lines.

After the focus of the Monoscope is set for maximum resolution, the resolution of the video amplifier can be checked. This is done by making the Monoscope scanning normal size and increasing the scanning on the Kinescope. The latter is necessary to remove the possible limitation of Kinescope resolution. If a test pattern is used, the resolution of the amplifier is easily checked by noting the resolution of the "V" in the upright position. The resolutions of the

Monoscope and video amplifier should be appreciably more than the resolution to which the Kinescope is to be rated. Under these conditions, the limits of the Kinescope resolution can be determined and reliable test data obtained.

Experience has shown that the resolution in all parts of the scanning pattern on a Kinescope may not be uniform. Each section carries "V's" which correspond to resolutions of 150 to 450 lines. Also, tones between black and white are included to give a check on the modulation characteristic. With such a pattern as this, the Kinescope can be rated under different bias conditions with various amounts of video signal input. An illuminometer can be used to check the light output for a definite signal. Experience has shown that such elaboration is necessary to obtain reliable test information. Perhaps, as the art progresses, suitable short-cut tests can be devised.

RECEIVER TESTS

A standard source of high-quality signal has numerous advantages in the development and production testing of receivers. Various resolution patterns serve as good "yardsticks" for measuring receiver characteristics if they can be converted into video signals of good fidelity. As has been pointed out, the Monoscope is particularly useful for this purpose. By adding standard synchronizing impulses to the Monoscope signal and modulating a small transmitter, a very useful test signal can be obtained for readily checking the receiver.

TELEVISION SYSTEM TESTS

When a television system is installed, numerous tests must be made to adjust the various circuits. The Monoscope materially aids such testing. For instance, any extraneous signals entering the grid circuit of the Iconoscope can be easily detected. Since the video signal from the Monoscope is directly proportional to the beam current, any variation in beam current is revealed as a modulation of the video signal. Therefore, any extraneous signal or hum in the circuits is revealed.

THE PHOTO-ELECTRIC CELL

THE most common forms of energy are mechanical energy, heat, chemical, electrical, magnetic, sound and light energy. Some of the things we wish to do with these forms of energy are, to capture them from their natural sources, to store, transport, transmit, measure, record, observe, control, transform them into other forms of energy, and to control one form of energy by another. For example, mechanical energy exists in the form of water flowing in streams. We capture this from nature by hydraulic turbines. We store this by holding the water at an elevation in reservoirs. Mechanical energy is carried in storage by everyone who has a watch.

The effects of mechanical energy are common to observation. Its control is commonly by clutches, brakes, etc., and it controls other forms of energy by means of electrical contacts, triggers on guns, etc. That is to say, a small amount of mechanical energy applied to the trigger of a rifle controls a large amount of chemical energy. A similar story might be written about other forms of natural energy. But when we come to energy in the form of light, we find that the story is rather brief in spite of the fact that light energy is perhaps one of the most important to the human race.

LIGHT ENERGY

Light energy is captured from nature almost solely by plant growth. To store it, except in minute amounts by phosphorescent chemicals, is impossible. Since it cannot be stored, it cannot be transported in storage. It transmits itself, but its measurement is a thing of considerable difficulty, and recording is even more difficult. To control its formation from other forms of energy is usually relatively easy, but for it to control any other form of energy is very difficult. Its transformation into

other forms of energy is greatly limited by lack of suitable means.

In this discussion of light we must not forget that light, as ordinarily accepted, is distinct from radiant heat, and hence the energy as light is really quite small. If heat be absorbed out of sunlight, the remainder is a very small amount of energy. This energy cannot be transformed into usable mechanical energy. It may be transformed into heat, but the resulting heat is very small. It is transformed into chemical energy by many natural processes of growing tissues, especially in plants. It never makes a sound, it has no magnetic effect which can be detected by ordinary magnetic detecting devices, and it is transformed from one wave length of light to another with extreme difficulty.

From this one sees that while light energy is of such great importance to the human race, the things which it can be made to do are greatly limited. It can make us see, it can be recorded by a camera and it can be transformed into electrical energy by the photo-electric cell.

How brief a recital this makes compared with the recital of electric energy, which can be transformed quickly into other forms of energy, which by simple means controls almost any form of energy, and yet which itself is by nature so infrequently applied to the human system. It is very fortunate for us that one of our first light detecting instruments—the photo-electric cell—controls so universally applicable an energy as electricity. The human race has had for many years mechanical prime movers, mechanical legs and arms, and it has had electrical heaters, chemical heaters and so on, but the human race has been dependent upon the human eye for its detection and record of light. If the photo-electric cell can be made by a simple process to take the place of the human eye in certain places, it can be of great service to mankind.

Photo-Electricity

The term photo-electricity was at one time used to describe any electrical effect due to the action of light. Much progress

in the study of such electrical effects has been made in recent years and a definite terminology has been established for the various electrical actions due to light. Exact physical science now requires that the term "photo-electric phenomena" be applied only to those effects in which there is electronic emission (emission similar to that from a radio tube filament) from a sensitive surface which is exposed to light or other electromagnetic radiation, such as X-rays.

Other types of light sensitive devices are those dependent upon the actino-electric or photo-resistance effect, and the photo-voltaic or photo-electro chemical effect. Of the former, the selenium cell is the most prominent. In this cell the resistance of solid selenium varies upon exposure to light.

The photo-voltaic cell is essentially a primary battery, the voltage of which is produced only upon exposure to light. This effect was studied more than sixty years ago by Becquerel and subsequently by others. Although less has been done with this type of light sensitive device than with the selenium or photo-electric types, it is possible that important developments may be made which will make this phenomenon extremely useful.

Cell Action

The action of the true photo-electric cell is quite different from that of either of the two types of light sensitive devices mentioned above. In 1887 Hertz observed that an electric spark was more easily passed between electrodes when they were exposed to ultra-violet light. Later, Hollwachs discovered that a negatively charged body lost its charge under similar conditions. From this meager beginning, many facts concerning the phenomena of photo-electricity have been brought to light, including its explanation on the basis of modern electron theory.

Although most substances show the photo-electric effect to a certain degree, the electron emission from alkali metals and hydrides of these metals due to the action of light in the visible spectrum is far more pronounced than that from any other known substance. Photo-electric cells having sensitive sur-

faces of the alkaline metals are therefore in most common use, and the term "photo-electric cell" is generally understood to be one of this type. There are many variations in sizes and shapes of such cells which have been designed to meet particular physical requirements. Within moderate limits, however,

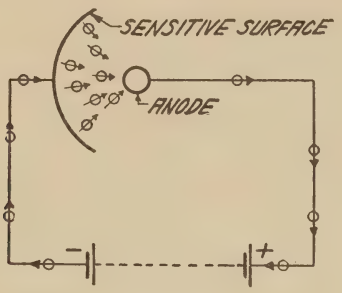


FIG. 129

the size or shape of the cell does not materially affect the sensitivity.

At the present time, there are several distinct types of cells as regards the physical construction, location of the sensitive surface and method of preparation of the same. In one type a thick film of the alkali metal is deposited directly on the inner wall of a glass envelope. Various means are utilized in making electrical contact between the lead-in wire and this surface. In another form, a non-sensitive metal, such as silver, gold, or magnesium, is first deposited on the inner wall of the bulb, on top of which a thin layer of photo-electrically sensitive material is placed. In a third form the sensitive material is deposited on a metallic plate which is mounted within the envelope.

In all cases the sensitive surface is made the negative terminal or cathode of the cell, and a second electrode in the form of a straight wire, loop, or mesh is mounted in front of the sensitive surface. The latter electrode is the positive terminal, or anode.

In preparing the cell, the bulb must be very thoroughly

evacuated before depositing the sensitive surface. All glass and metal parts are thoroughly outgassed by ovens and inductive heating. The sensitive materials used must be prepared in a vacuum at the lowest obtainable pressures possible with mercury vapor pumps backed by high speed oil pumps. The degree of evacuation and time of pumping is much greater than that for most other vacuum products, such as radio tubes.

When a cell is connected to a battery, as in Fig. 129, electrons are emitted from the sensitive surface and are attracted to the anode when the surface is illuminated through the window of the cell. This flow of electrons from the sensitive surface to the anode and continuing through the external circuit comprises the photo-electric current. If the light is cut off from the cell, the current drops to zero immediately.

The cell, as described above, is purely an electron emitting device, fundamentally similar to the familiar vacuum valve commonly known as a radio or amplifier tube. In the latter device, thermionic emission is controlled by grid voltage. In the cell photo-electric emission is controlled by the quantity and color of light energy entering the window. The speed of re-

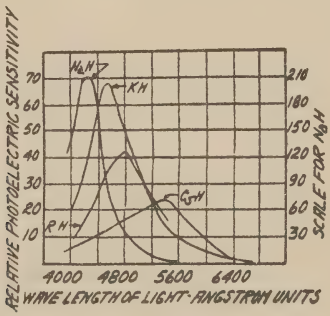


Fig. 129A

sponse of the vacuum photo-electric cell may therefore be compared favorably with that of a radio tube. Exact measurements of time lag, (if there is an infinitesimally small one) are difficult as it is nearly impossible to obtain a modulated light source and other electrical equipment, whose time lag is

more definitely known than that of the cell. Relative measurements are quite possible, however, and it is from such a method that comparisons have been made between the true photo-electric cell and other types of light sensitive devices. The photo-electric cell has been found to respond to very high fre-

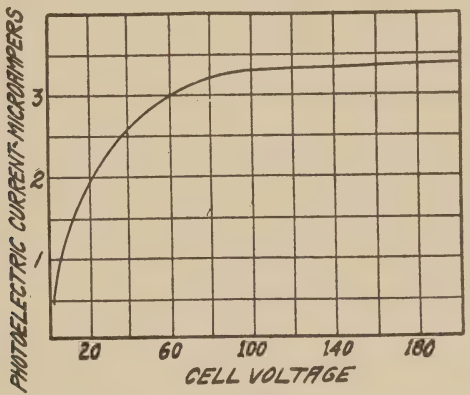


FIG. 129B

quencies more satisfactorily than any type of actino-electric, or photo-voltaic cell. With the latter types, it is found that the intensity of current signal from the cell is attenuated as the frequency of the constant intensity light signal is increased.

As mentioned above, the response of alkali metal cells is determined not only by the quantity of light but also by the quality or color of the light.

In Fig. 129A are shown color characteristics of alkali metal hydride cells in which there is a thick film of the metal. It will be seen that the hydrides of the various alkali metals—cæsium, rhubidium, potassium, sodium, and lithium—respond to various wave lengths of radiation, *i.e.*, to different colors of light, with different sensitiveness. Cæsium hydride has maximum sensitivity with yellow light (wave length: 5,400 Angstrom Units), while sodium hydride has maximum sensitivity with violet light (wave length: 4,200 Angstrom Units).

Potassium hydride has maximum sensitivity under the influence of blue light (wave length: 4,600 Angstrom Units).

Recently it has been found that the color sensitivity characteristics of alkali metal cells are very different in the case of thin films and in combination with other non-metallic chemical elements. Very important developments are being made on such types of cells with which the sensitivity to yellow and red light is being greatly increased.

Vacuum and Gas-Filled Cells

With reference to electrical characteristics, there are two general classes of photo-electric cells.

The vacuum type, as the name implies, contains no gas. The gas-filled cell, however, is filled to a low pressure with an inert gas such as helium, argon, or neon. In this type of cell, the photo-electrons ionize the inert gas in their passage

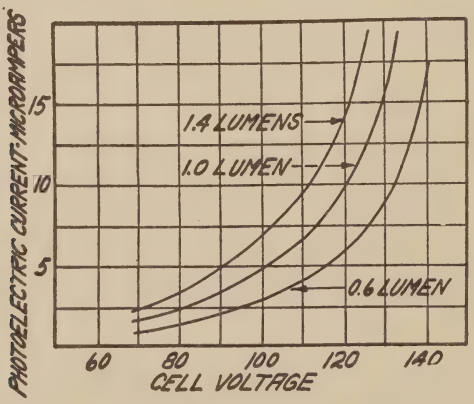


Fig. 129C

from the sensitive surface to the anode. The resulting ionization current is added to the electron current, giving a larger total photo-electric current than in the vacuum type of cell. Photo-electric cells of maximum sensitivity are therefore of the gas filled type.

The magnitude of the photo-electric current in the gas-filled cell depends upon the specific surface sensitivity; color of light, the volume, pressure, and nature of the inert gas; cell voltage, and the total light flux entering the cell. In the vacuum cell the current depends only upon the surface sensitivity, color and amount of light, and to a certain extent upon the cell voltage. However, as there is no ionization in the vacuum cell, the sensitivity does not materially increase after the saturation voltage is reached.

Electrical Characteristics

If the photo-electric current of a typical vacuum cell is plotted against the applied cell voltage with a constant source of illumination, the curve of Fig. 129B will be obtained. The sensitivity of the cell increases as the voltage is raised to approximately 100 volts above which the sensitivity is practically constant. The vacuum type of cell is therefore used where the cell voltage is subject to frequent fluctations or in exact quantitiative work where greatest constancy of cell sensitivity is required. The vacuum cell does not have as high sensitivity as the gas-filled cell, however, because the photo-electric current is due only to photo-electrons and does not include any ionization current.

In Figs. 129C and 129D are shown the principal electrical characteristics of a typical gas-filled cell. If the cell is connected in the circuit of Fig. 129E with a constant source of illumination, the relation between the cell current and cell voltage will be as shown in Fig. 129C. If the voltage is increased to the point where the curve rises very steeply (almost vertically, the cell will glow visibly and would destroy itself due to excessive current and heating were it not for the protective resistance, R, in the circuit. For this reason, the gas-filled cell should never be operated without such resistance or some other current limiting device in series.

Referring to Fig. 129D, it is seen that if the cell voltage is maintained at a constant value, the cell current is directly proportional to the total light flux entering the cell. This

linear characteristic is very important and is used in a variety of applications.

Operating Requirements

From Figs. 129C and 129D, it is noted that for a given light flux, the cell current or cell sensitivity is greater, the higher the voltage. Also, the greater the light flux, the lower the voltage at which the cell will visibly glow, which condition

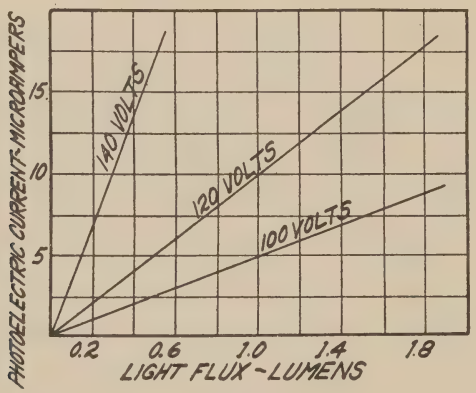


Fig. 129D

is indicated by the steep portion of the curves of Fig. 129C. Since the sensitivity increases with the cell voltage, it is desirable to operate the cell at the maximum safe operating voltage for the given illumination. For best operation this voltage must be determined for the particular conditions under which the cell is to be used.

There are several available methods for determining the maximum safe operating voltage. With the maximum illumination which is ever to be used, while the cell voltage is applied, the current voltage characteristics of Fig. 129C may be determined, using the circuit of Fig. 129E.

In a second method the maximum light flux to be used is allowed to enter the cell and the voltage raised until the visible

glow is produced. As it is difficult to see the glow when the cell is illuminated, this effect can be detected by alternately covering and uncovering the cell window while the cell voltage is raised in small steps. Until the condition of sustained glowing is produced, the current will drop to zero each time the light is cut off. When the voltage is raised to the point where

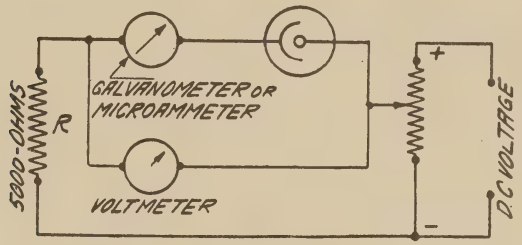


FIG. 129E

there is sustained ionization, the meter will show that a current is passing after the cell is darkened. The voltage should then be immediately reduced until glowing discontinues.

A third and probably most satisfactory method for determining the light glow voltage is that shown in the circuit of Fig. 129F. Again, with the maximum light flux entering the cell and with the push button switch S closed, the potentiometer R3 is slowly moved from left to right. The voltmeter V should have a high resistance, namely 500 to 1,000 ohms per volt. As the voltmeter needle rises it should be closely watched, as there will be a sudden decrease in its reading at exactly the time the cell begins to glow. This is due to the fact that the additional current drawn by the cell when glowing is sufficient to produce a voltage drop in the resistance R2. As soon as the needle drops back slightly, the switch S should be opened to prevent injury to the cell due to glowing. With the opening of this switch the voltmeter again rises to the value at which the cell began to glow. This value is the light glow voltage which was also determined by methods described above and IT IS NOT THE SAFE OPERATING VOLTAGE

for this amount of light. The maximum operating voltage is from 10 to 25 per cent below the light glow voltage and should in all cases be the lowest value that will produce satisfactory results. In this way the life of the cell is greatly lengthened and the danger of interruption of service due to the photo-electric trouble is materially lessened.

Much has been said regarding the life of photo-electric cells as well as a comparative merit of photo-electric, actino-electric, and photo-voltaic cells. Regarding the life and quality of the photo-electric cell, it is undoubtedly true that the purity of materials and care in manufacture are determining factors of first importance. To make possible accurate comparisons between various types of photo-electric cells, the practice of expressing their sensitivity in terms of microamperes per lumen of light flux has been established. As there are great differences in color sensitivities of various cells it is customary to specify the type of light source with which the measurements are made. A typical light source for such work is a tungsten filament operating at 2,700 or 2,800 degrees absolute (2,427

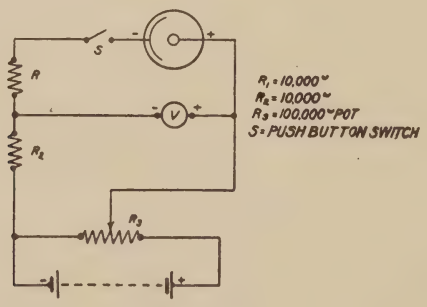


FIG. 129F

or 2,527 degrees centigrade). In the case of gas-filled cells it is also necessary to specify the voltage at which the tests are made in terms of a percentage of the light glow voltage for a particular quantity of light. As a further precaution against damage to the cell, care should be taken to keep cells in a reasonably cool place.

AMPLIFIER SYSTEMS

Audio amplifiers in use today are known under various classifications determined by their function relative to the intensity of the signals passed through them. The form of coupling is very important as regards the placement of an amplifier in a complete system and many complete amplifiers consist of several amplifying units employing different forms of audio frequency coupling.

The form of coupling, that is the method of transferring the energy in one amplifying tube to the succeeding tube, does in many cases influence the position of the amplifier with respect to the entire system because of the special tubes used in conjunction with that form of coupling. Because of the influence of the coupling medium, amplifier circuits are referred to according to the name denoting the form of interstage coupling. No matter what the form of coupling, it is not imperative that a complete amplifier make use of that arrangement. It is possible to employ several forms of coupling in a single multi-tube system or if so desired by the designer of the amplifier, one form of coupling may prevail through the entire system.

Resistance Coupling

The simplest yet a very effective method of audio frequency coupling or amplification, and in use in many systems, is that known as resistance coupling. This system involves the use of a fixed resistance in the plate circuit of a vacuum tube, as shown in Fig. 130. This complete circuit is very similar to that shown in Fig. 119A. As a matter of fact it is a duplication of this circuit with a few changes.

The batteries designated as "A," "B" and "C" in each tube circuit are the filament, plate and grid bias batteries respective-

ly. The minus terminals of each B battery are joined thus making common all battery potentials at this point, and an electric path connecting tubes 1 and 2. While it is not customary in practice to employ individual sources of operating voltage as illustrated, we use this system because we have not reached the stage where it is possible to use common batteries and other sources of potential. E is a source of voltage fed into tube 1. An examination of each circuit shows that each grid filament and plate circuit is complete, the electronic stream within the tube providing an electric path between the filament and grid and the filament and the plate.

We know that an alternating voltage applied at E will cause the flow of alternating current in the plate circuit of that tube.

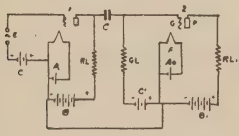


FIG. 130

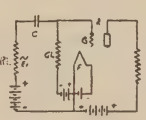


FIG. 130A

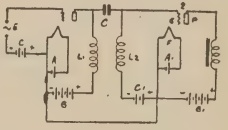


FIG. 130B

That means that an alternating current will flow through the resistance RL. The operating axis in the grid circuit of tube 1 is provided by the C battery. The B battery provides the required plate potential for tube 1, the steady D.C. plate current flowing through RL. Thus this resistance carries two currents, A.C. due to E and D.C. due to the voltage of battery B. Since current flows through this resistance, two voltage drops are also present across this element. One is A.C. and the other is D.C.

An examination of the diagram shows that one side of the filament circuit of tube 2 is electrically connected through bias battery B, to the resistance RL. This is the common B minus terminal. A further examination of the circuit shows that the grid of tube 2 is also connected across RL, via the condenser C. In other words, we have a circuit such as that shown in Fig. 130A, where tube 2 is actually connected across a source of A.C. such as E1, which in this case is nothing more than the A.C. developed across RL, when the alternating

voltage E is applied to the input circuit of tube 1. Hence RL of tube 1 is a source of A.C. for tube 2. The value of A.C. voltage designated as E1 in Fig. 130A is equal to that value determined by the formulæ quoted in the chapter devoted to voltage amplification with a resistance load applied to the tube.

Hence the A.C. voltage across RL is applied across the grid filament circuit of tube 2 via the condenser C. It is obvious that the condenser C serves two purposes. First as a means of transferring A.C. voltage to the grid of the tube and second as a means of isolating the grid of tube 2 from the positive potential of battery B which would otherwise be applied to the grid of tube 2 and impair operation of the tube causing great distortion, if not damage to the tube. Thus it is both a coupling condenser as well as an isolating condenser.

The fixed resistance GL is known as the grid leak or grid circuit resistance and likewise serves a definite purpose. If this resistor is removed, a definite D.C. voltage cannot be applied to the grid of the tube in order to set its operating axis. Without the resistance G.L. the grid can assume any value of voltage compatible with the voltage in the grid circuit. Such a condition equivalent to an open grid would cause distortion. To prevent what is known as a "floating grid" the resistance GL is employed as a means of applying the negative bias from battery C1, so as to adjust the operating axis of the grid to conform with the A.C. voltage secured from RL and to provide distortionless amplification within the tube.

Several significant facts are evident in the drawing. First, recalling what was said about the action of condensers in A.C. circuits, a charging current will flow around the condenser C and a voltage drop will be present across its reactance. This drop will then be subtractive from the total voltage secured from RL and less voltage will be applied across the combination GL in parallel with the grid and filament of tube 2. It is therefore necessary to make the reactance of C, by judicious selection of its capacity value, so low that the voltage drop across it is minimum.

The voltage applied to the input of an audio frequency amplifier tube, representing the electrical equivalent of sound

waves, is not of a single frequency, unless such a condition is deliberately desired. Hence the reactance of C will vary with the frequency of E and a variable voltage drop will ensue. If however the reactance of C is low at the lowest frequency encountered in the circuit, satisfactory operation will be secured.

We know that the value of RL must be at least 10 times the plate resistance of tube 1, in order that the maximum A.C. voltage be applied across RL. The reactance value of C must be minimum at the lowest frequency. Furthermore, the reactance of C must be small in comparison with the impedance between GF with the grid leak GL in parallel. Relative to the impedance between GF, the grid and filament of the vacuum tube, these two elements, although small in physical dimension, nevertheless constitute a small condenser possessed of reactance as well as resistance. The presence of a similar capacity between the grid and the plate in a vacuum tube such as the three element structure being considered introduces a coupling between the output circuit of the tube and the input circuit. The extent of this coupling and its effects depend entirely upon the tube constants and the elements connected into the respective circuits, particularly into the plate circuit.

Strange as it may seem, the input tube capacity is really of two values; 1, the static capacity between grid and filament, that is, the element coil without any device connected into the grid or plate circuits, and the effective input capacity when the filament is incandescent and a device is connected into the plate circuit. As it happens the effective input capacity may be several times the static capacity and since this capacity is in shunt with the grid leak GL, it tends to reduce the total impedance of the input circuit, thus reducing the amplification and reflecting back upon the action of RL. This condition is most pronounced upon the upper audio register, that is upon frequencies in excess of 2,000 cycles.

While all of this data is not relative to actual amplifying equipment already in service it is of interest with respect to new equipment or experimental work. Empirical determinations show that three stages of low Mu tubes, give a better

operating characteristic on the high frequencies than three high Mu tubes. On the low frequencies it is necessary to consider the reactance of the condenser C, so that the voltage drop across it is small.

Bearing in mind the fact that as the Mu of the tube increases, the permissible input voltage decreases. When used, the high Mu tube should be nearest to the input voltage where the input is the lowest.

The determination of the voltage ratio possible in a resistance coupled amplifier is interesting and affords a method of determining the value for C, so that as far as the coupling unit is concerned and neglecting the effect of the input tube capacity, a certain ratio of voltage transfer is available over a predetermined audio band. In other words the variation in voltage transfer through the stage should be of a predetermined value, say 10 per cent over a predetermined audio band. The maximum voltage ratio in the stage is secured when the value of C is infinitely large and then is governed by the resistances employed in the coupling unit. The value of C is always finite, hence the maximum voltage ratio is never possible, but is most closely approximate at the high frequencies, when the reactance is low.

The illustration in Fig. 130 shows two amplifying tubes. Each one of these tubes constitutes a stage of amplification. The same method of classification applies to all other forms of coupling as well, but it is necessary to remember that each stage may employ more than one tube. The best method of determining the number of stages in a system is to ascertain the number of complete coupling units in the system, neglecting the device which connects into the first tube but counting the coupling device which links the output tube with whatever is connected to it.

Although the subject of resistance coupling is not wholly completed because there are numerous ramifications of this form of amplification we shall pass onto the next system. However before closing temporarily, the subject of resistance coupled amplification we wish to state, that such amplifiers are usually arranged in sets of two or three stages and are not

limited to operation with battery sources of operating potential but are used with all sorts of devices which supply the required voltages.

In addition, because of the character of the amplifier, it is customary to employ high Mu tubes as the amplifiers, although such an arrangement is by no means compulsory and many resistance coupled systems employ standard amplifying tubes.

Reactance Coupling

Another popular form of radio frequency amplification is reactance of impedance coupling. These terms are applied to signify that the coupling units linking the tubes in the amplifier are coils sometimes designated as choke coils and the amplifier is known as "choke coil coupled."

Generally speaking the circuit diagram of a tube system is shown in Fig. 130B. L1 and L2 represents the chokes or inductances, usually referred to as the impedances, in the plate and grid circuits of the amplifying tube. Two such units in conjunction with the isolating condenser C constitute a complete coupling element employed to link two tubes. The similarity between this circuit and that shown in Fig. 130 requires no discussion. The voltage E applied to tube 1 causes an A.C. voltage across L1, which being located in the plate circuit is known as the plate choke. This voltage is then applied across L2 and GF of tube 2. L2 being in the grid circuit of tube 2 is designated as the grid choke. The previously mentioned name is still applicable to the condenser C. It still functions as a coupling and as an isolating condenser.

The position of the inductance L1 and L2 is not standard in all systems. The only thing which is standard is that the inductance values of L1 and L2 are quite high, iron cores being employed, so that good voltage transfer takes place between tube 1 and L1, and that the effect of L2 upon L1 will be minimum on the higher frequencies and so that the impedance of L2 will be with respect to the grid filament impedance of tube 2. Generally speaking L1 and L2 are so located, even when within a single housing that there is not inductive coup-

ling or electromagnetic induction between the coils, the only transfer between the two circuits being that via the coupling condenser C and the return circuit. Such an arrangement makes L1 independent of L2. Such a state is frequently secured by employing two separate inductances contained in two separate housings.

A few words might be of interest in connection with the usual method of applying such coupling in an audio frequency amplifier. One popular arrangement is to employ tuned impedance coupled amplification. This is arranged in the following manner.

In contrast to the function of C in the resistance coupled system, the variation in resistance of C has very little effect upon the performance of the device. In this system C is a part of a resonant circuit, resonating with L2 and constituting a series resonant circuit. We made mention in the section devoted to series and parallel resonance, that the voltage across the inductance in a series resonant circuit may be many times the original voltage at resonance. This phenomenon is utilized to good advantage, since the maximum voltage is always desired across L2, inasmuch as the tube is a voltage operated device. Furthermore, the increase in voltage at resonance, affords voltage step-up within the unit at the resonant frequency, despite the fact that the turn ratio between L1 and L2 is 1:1. This voltage step-up at a resonant frequency is made to serve a definite purpose.. By setting the resonant frequency at say some value between 30 and 100 cycles, it is possible to compensate for the low frequency deficiency of the magnetic type of loud speaker, because the amplifier will accentuate at and around the resonant frequency.

Since inductive coupling between L1 and L2 is eliminated and the performance of the system is governed by the L2—C circuit, the effect of L1 is neglible, other than to provide the voltage for application across L2—C. Since 90 per cent voltage transfer is available when the external impedance (reactive) is numerically equal to 3 times the tube plate resistance, and since the average choke represented by L1 is rated at from 200 to 1,500 henrys and is used with tubes having plate re-

sistance values between 5,000 and 12,000 ohms, the variation in voltage transfer between the tube and the load over the normal audio band, between 40 and 10,000 cycles is entirely negligible. Hence for the purpose of analysis we can consider a uniform voltage to be available across the input of L2—C.

The electrical circuit of the tuned double impedance unit as shown in Fig. 130B is illustrated in Fig. 131. For the sake of simplicity we will imagine pure reactances for L1 and L2, omitting the effective resistance of these two chokes. Their presence influences the magnitude of voltage step-up, but whatever the normal values, voltage increase at resonance is

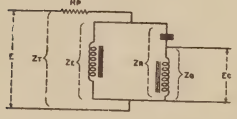


Fig. 131

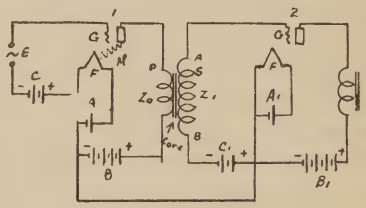


Fig. 131A

secured within the coupling unit. E is the voltage available from the tube and applied across the circuit. Rp is the plate resistance of the tube. Eg is the voltage available across the grid choke for application to the grid of the succeeding tube.

As in the case of the resistance coupled arrangement, the system is not limited to one or two stages. Three and four stages may be employed if desired and it is not essential that the complete amplifier be impedance coupled merely because one stage is of that type. It may be combined with any other popular system.

Reactance coupled amplifiers like resistance coupled amplifiers make use of high plate circuit load impedances, hence allow the use of high Mu tubes as voltage amplifiers in the quest for maximum amplification with minimum tubes. One must remember that the higher the amplifying power of a tube, the lower the input grid voltage, unless of course a very high value of plate voltage is employed.

With respect to the amplification available in conventional reactance coupled audio amplifier, assuming that voltage step-up on a certain frequency is not available in system, the actual amplification is that obtained from the tubes. The inter-stage reactance coupling units do not provide amplification within the coupling unit. The maximum amplification is unity or 1, being the equivalent of transferring the voltage output of tube 1 to the grid circuit of tube 2. If each of these tubes has a Mu of 8, the voltage amplification in the system will be 8×8 or the Mu of tube 1 times the Mu of tube 2. We assume that the full Mu rating of the tubes is being secured, although in actual practice this does not hold true, if the frequency of the voltage input is low. However, because of the fact that the impedance of the average plate load (choke coil) is about 6-10 times the tube impedance, the difference between the secured 95 per cent and the maximum 100 per cent voltage transfer is so small that it is safe to consider the voltage amplification ratio of the tube-coupling unit combination equal to the Mu of the tube.

Transformer Coupling

The most popular form of audio frequency amplification is transformer coupling, wherein a transformer with two windings a primary and a secondary link two tubes, as for example in Fig. 131A. While the structure of an audio frequency transformer differs in certain respects from that described in a previous section devoted to transformers, the general principle of operation is the same. Current flows through the primary of the transformer by virtue of the A.C. component in the plate circuit of tube 1. This primary therefore passes the D.C. plate current due to the battery B and also the A.C. current due to the signal input voltage E. The flux due to this current cuts the turns of the secondary and introduces a voltage across the terminals A and B, which is then applied to the grid filament circuit of tube 2.

The number of turns constituting the secondary winding is greater than the number employed for the primary winding.

Since the voltage produced in the secondary winding because of the action of the primary flux is proportional to the ratio of the turns on the windings, the output voltage of S, the secondary is greater than the voltage input into P, the primary. This means that voltage set-up is secured in the coupling unit. This is in direct contrast to the various coupling devices mentioned thus far, particularly when we realize that this voltage step-up is available at all frequencies passed into the primary. Like the resistance or reactance method of amplification the transformer when employed as a link to audio tubes, operates in a voltage amplifying system. As is evident in Fig. 131A, the primary and secondary windings are individual and apart. The only link between them is electromagnetic induction. Hence it is unnecessary to employ an isolating condenser between the plate end of the primary winding and the grid end of the secondary winding. Since the two coils are not electrically connected, the plate potential applied to the primary cannot find its way to the grid of the second tube unless a defect develops within the unit, whereby the primary and secondary windings come into direct electrical contact.

Realizing that maximum voltage amplification is desired one would imagine that the highest possible turn ratio is employed in the audio unit, just as in the power transformer discussed in a preceding chapter, the turn ratio is based solely upon the output voltage desired. Such however is not the case. While it is true that the turn ratio can be increased to any extent within the breakdown limits of the insulation between the turns and the windings and high voltage step-up would be secured in the transformer, that practice is impossible in a transformer designed for sound amplifying systems. The reason for this is the frequency requirement of the transformer unit. Whereas the power transformer functions upon but one frequency, that of the power supply feeding the input voltage to the primary, the audio frequency transformer must perform over a band of frequencies, representing the full range of all musical instruments and speech. (Qualification of the musical range is necessary because the modern audio transformer will not operate efficiently below C_3, the third octave below middle C, the

32 cycle note.) The requirement of full frequency range introduces complexities into the design, items which are considered of little consequence in the conventional power transformer.

A high turn ratio is not conducive to operation over a large audio frequency band with equal facility. That is, the degree of amplification secured within the unit, despite the fact that the turn ratio is constant at all times, is not the same over the entire band. This condition is due to several reasons, allied with the electrical design of the unit, and its associated circuits.

Consider for a moment the problem of turn ratio and voltage amplification within the unit. The first specific requirement for an audio frequency transformer is that the impedance of the secondary winding be as high as possible, so that it transfers the maximum voltage across the grid-filament circuit of tube 2. The second requirement be that in order that the voltage output of the transformer be maximum that the voltage input be maximum, namely that the transfer of voltage between the plate circuit of tube 1 and the primary of the transformer be as high as possible. This is accomplished by making the impedance of the primary as high as is consistent with design. Thus we have maximum secondary impedance which means inductance and number of turns, and maximum primary impedance which means inductance and number of turns. However, one cannot make the number of turns used in the primary of a huge amount. This is so because a small capacity is present between the individual turns of this winding and between layers of this winding. This capacity is known as the distributed capacity, and is present wherever a number of turns are wound upon a coil. Such a capacity in shunt with the secondary winding would tend to offer a path of low impedance for some of the higher audio frequencies and they would not be applied across the grid-filament of the tube, hence a loss of high notes. Thus we find a definite limitation in the number of turns which may be employed for the secondary winding. It is true that efforts have been made to so wind the secondary turns that this capacity is minimized, but the limitation is present nevertheless.

With a definite maximum for the number of secondary turns,

it is logical that if the impedance of the primary is to be as high as possible, that a large number of turns must be used. If this is done, the turn ratio between S and P will not be very great and the voltage step-up will not be as great as might be desired. Thus we find a limitation in the primary winding as well as the secondary winding. This is overcome by various means. First as the acceptance of a definite turn ratio and voltage ratio as being satisfactory. Second is the use of an alloy core instead of silicon steel, whereby a large inductance and impedance are produced in the primary winding with fewer turns.

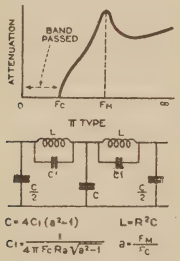


Fig. 142

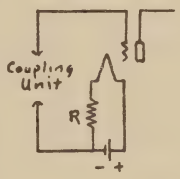


Fig. 143

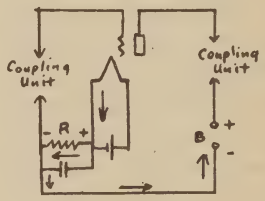


Fig. 144

When determining turn ratio, the turns in the secondary remain intact; those in primary being decreased to increase the turn ratio. Each such increase in turn ratio means a reduction in the voltage transferred from the tube to the primary because the impedance relation between the tube plate resistance and the load impedance is impaired. Hence, while the turn ratio of a transformer may be increased from 3 to 6, the actual voltage output out of the secondary winding when the ratio is 6:1 may be less than when the ratio between the secondary and the primary is 3:1 because a lower voltage is transferred from the tube to the primary of the transformer. The ratio of the modern high quality audio frequency transformer is seldom greater than 3.5:1. In many cases it is as low as 1.5:1.

Another effect that displays a large influence upon the operation of the transformer is that the primary flux does not link with all of the turns of the secondary winding. The greater

the turn ratio, the greater is the number of turns of the secondary winding which do not link with the primary flux. Thus we have a leakage of flux. This flux sets up a reactive voltage in either the primary or the secondary. This reactive voltage is the equivalent of a reactance introduced into either the primary circuit or the secondary and the term "leakage inductance" is applied to that portion of the self inductance of the primary or secondary which is due to the leakage of flux. The reactance of this inductance is known as the "leakage reactance." The greater the separation between the turns of the transformer windings the greater the leakage reactance. Now, in actual practice, the distributed capacity of the secondary winding resonates with the leakage inductance or reactance and produces a "peak" in the response curve of the transformer. This peak produces excessive amplification or voltage step-up due to series resonance at the resonant frequency. The lower the ratio of the transformer, the less the value of leakage inductance and since the distributed capacity of the secondary is fixed, the lower the value of L (the leakage inductance in this case) the higher the frequency of resonance. Conversely the higher the turn ratio, the lower this resonant frequency. As a matter of fact such resonant peaks are entirely undesired and modern transformer design is such that the amplitude of this peak or the extent of such undesired voltage step-up is greatly reduced. Wherever possible it is carried beyond the normal audio band, at least beyond 5,000 cycles. Such peaks accentuate signals around that frequency and cause amplitude distortion.

Another detrimental effect of leakage reactance is that the tube connected to the secondary of the transformer imposes a load upon the winding by virtue of the effect of the coupling device connected into the plate circuit of tube 2. This load alters the action of the secondary winding, changes the leakage reactance and there is a continual shifting of the peak of the transformer and operating characteristic. Such operating characteristics have been very well remedied in the modern radio systems because of the excellent design of the coupling unit.

METHODS OF SECURING GRID BIAS

EVERY amplifier tube requires a grid bias and the bias is the most important part of the tube employed to indicate the amplification available in system, that is the "gain" tube or the "level indicator" tube.

Consistent with the various methods of securing the other operating potentials various methods of securing grid bias voltages are available. All of the discussion carried on thus far employed the battery as the source of grid potential. We shall now dwell upon the other systems.

The first and simplest, is available when the tube filaments are operated with D.C. voltage, and direct current flows through the filament circuit. This system utilizes a resistance in the negative lead of the filament and the production of a voltage drop across this resistance, equal to IR, where I is the filament current and R is the resistance as shown in Fig. 143. This practice is seldom used in audio amplifying systems because the voltage available in this manner is too low, being governed by the voltage of the battery and the voltage required by the vacuum tube filament.

A battery system although used in but few cases, where the filaments are D.C. operated is shown in Fig. 144. Here we introduce the common method employed in A.C. installations. Referring to the illustration, the resistance R is located at such point, that the tube plate current must flow through the resistance before it completes the circuit to B minus. A voltage drop is therefore produced across R with its filament terminal as plus and its other terminal as minus. By connecting the grid return to the minus end, a bias (negative upon the grid) equal to $E = Ip \times R$ where E is the voltage, Ip is the plate current (steady value) and R is the resistance as applied to the grid. Suppose that the plate voltage is of such value that when

the grid bias is 6 volts, the plate current is 6 mils. Such values are always known, since they are provided in the tube manufacturer's literature and the correct value of grid bias is stated in all specifications. Since the required bias is known, application of Ohm's law for resistance with the tube plate current interpreted as I in the formula will produce the required value of R, *viz.*

Required E is 6 volts. The two plate current is 6 mils or .006 ampere. Then

$$R = \frac{E}{I} = \frac{6}{.006} = 1{,}000 \text{ ohms}$$

However the significant fact about this system is the path of the plate current. The fact that this current flows through

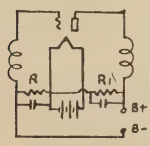


FIG. 145

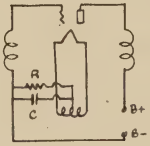


FIG. 146

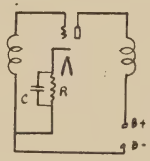


FIG. 147

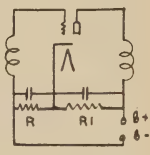


FIG. 148

R produces the bias. This resistance also carries the signal current and if allowed to be in the circuit will cause a voltage drop due to the signal current which will be applied to the grid of the tube as well as the regular grid bias. The phase relation between this A.C. voltage and the phase relation of the signal voltage will be counteracted by the A.C. voltage produced across the resistance and the apparent amplification of the system will drop. This is most noticeable on the low frequencies. In order to minimize such a condition, it would be necessary to add a bypass condenser across R, between the minus and plus terminals so as to offer a path of low impedance, which makes necessary a high value of C, as explained before. The D.C. tube plate current will flow through R, but the A.C. current variation will flow through C.

According to the computation for the bias resistance, the

requirement of a high bias for a low value of plate current makes necessary the use of a high value of resistance. This condition is overcome in the manner shown in Fig. 145. The action of R remains the same as before, but the addition of R1 increases the magnitude of D.C. flowing into R, thus enabling the use of a lower value of resistance and incidentally providing a means of increasing the current drain upon an eliminator without making the bleeder current too great. When R1 is not used the value of R is determined solely by the tube plate current. When R1 is used and the total current through R is the tube plate current plus that through R1. The first determination is the total available plate voltage and the voltage required for the grid. The latter is subtracted from the former and the calculations relative to the plate voltage are based upon the remainder. Then the current flow through R1 is determined by Ohm's law. Of course the item really determined is the value of R1, since the surplus current is known when the circuit is arranged. Hence

$$R1 = \frac{\text{total available plate voltage} - \text{required grid voltage}}{\text{total available current} - \text{tube plate current at known plate voltage}}$$

The resistance RI is in parallel to that resistance which governs the tube plate current and the total current which flows through R is therefore that through the tube plus that through R1.

Suppose that the tube used in an A.C. tube, operated with raw A.C. secured from a transformer. We are referring to the filament, as shown in Fig. 146. The grid bias is secured by means of a resistance located between the filament center tap and the junction between the B + /c minus and the grid return as shown by the location of R. Once more the tube plate current must flow through the resistance R before it can complete the circuit to the B minus of the B or plate voltage supply. The bypass condenser C across the grid bias resistance is shown. As is evident in Figs. 144 and 146 an open circuit in R will interfere with the plate circuit continuity and plate cur-

rent will be lacking. A short in this resistance or across C in each case will not interfere with circuit continuity, but the plate current will be high because the grid bias will be lacking. Distortion will of course be evident.

Now, let us consider the A.C. tube employing the cathode as the source of electrons. The filament is now a heater and does not supply the electrons. A resistance located in the cathode circuit as shown in Fig. 147 functions exactly as the resistance R in Figs. 144 and 146. The plate current flows through the cathode and a voltage drop is produced across the resistance R. The regular bypass condenser is also shown. If desired, this circuit may be amended as in Fig. 145 wherein another resistance is used to increase the current through R, thus minimizing its resistance value, illustrated in Fig. 148.

Perhaps we should mention at this time, that the use of the supplementary resistance R1 shown in Figs. 145 and 148 is used only when the plate circuit of the tube contains a resistance as the plate coupling medium, in which case the plate current is low and a comparatively high bias resistance is required. Another use for the resistance is in connection with screen grid tubes or in level indicator tubes where in the first case the plate impedance is high and the plate current is low, and in the second case when the plate voltage is normal and the grid bias much greater than normal.

Such grid bias arrangements are not limited to one tube. They may be employed in connection with several tubes, providing that the filament voltage for that group of tubes is secured from one source. Such an arrangement is shown in Fig. 149. The grid returns for all the coupling units are made common and junction is at one point, making contact with the minus end of the grid bias resistance. The plate circuit coupling units need not be shown at this time. This circuit however is suitable only when the tubes employ the same grid bias, that is, the same value of grid bias voltage. The value of R is now determined by dividing the required grid bias voltage by the sum of the plate currents of tubes 1 and 2.

In the event that the tubes are of the cathode type, the circuit arrangement is as shown in Fig. 150. If so desired individual

grid bias resistances may be employed in each cathode circuit as shown in Fig. 151. The two minus ends then terminate at a common B minus. Each such resistance requires a separate bypass capacity C.

When the two cathodes are joined and employ a common grid bias resistance, the current through this resistance is the sum of the plate currents of tubes 1 and 2. When they are individual, the current through the resistance is the plate current of the individual tubes. As in the case of the filament type of tubes, a common resistance can be employed only when the grid bias voltage is the same for both tubes.

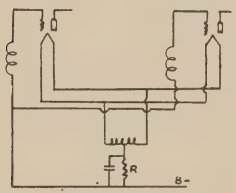


FIG. 149

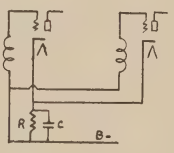


FIG. 150

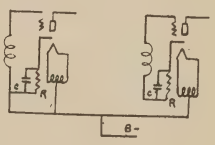


FIG. 151

As is evident in the illustrations, the arrangement of the plate circuit is of little importance, that is whether the tubes are in parallel or in push-pull. The governing factor is the source of the current flowing through the grid bias resistance. Push-pull and parallel plate circuits shall be shown in the chapter devoted to amplifier.

As an item of interest however, more than two tubes should not be operated from one common grid bias resistance, because if possible variations in tube constants and consequent unbalancing of the respective tube circuits.

In some instances, the grid bias voltage is secured from the eliminator. How this is accomplished is shown in Fig. 152 and the arrangement is employed if two or three different C (grid) bias voltages are secured from the same eliminator. We show the voltage divider network of the eliminator rather than the complete system, because the filter is of no importance in this discussion. Whatever is evident in connection with one tube is

true in the case of others of similar design. We have combined the cathode grid bias with the eliminator grid bias in order to illustrate how two different systems are arranged. According to the illustration, the tube employing the grid bias resistance in the cathode circuit secures its plate voltage from the B plus 2 terminal. The plate current for tube 1 returns to the B eliminator at the B minus terminal, but the plate current for this tube must first flow through R and the grid bias for tube 1 is secured across this resistance. The plate current for tube 2 also flows in at the B minus terminal as indicated by the double arrows.

All of the plate currents and the bleeder current as well flow past this junction and before passing back to the rectifying system, must pass through the resistance RL. This resistance then carries the entire output current of the eliminator. Since all the B plus terminals are positive with respect to B minus and since the direction of the current flow remains the same, the point B minus is then positive with respect to the point C minus. A drop is therefore produced across R1, with its positive polarity at the B minus terminal and negative at the C minus terminal. This bias voltage is then applied to the grid of the tube 2. While this circuit system is very much like that shown in 150 the difference is found in the fact that the regular B minus terminal is no longer the B minus terminal for the grid return of tube 2. The total eliminator output current produces a voltage across R1, which in effect is located as shown by the dotted lines in the grid circuit of tube 2 and is functioning as a source of voltage. A distinct difference between this and the regular grid bias system is that the calculation of the resistance R1 is not based upon only the plate current in tube 2 but all of the tube plate currents and the bleeder current as well. This system is employed to supply several bias voltages for different tubes by tapping R1 at various points. The calculation of R1 or its sections is based upon Ohm's law for resistances.

As a point of interest, defects frequently develop in such resistances and an open circuit removes the entire load upon the B eliminator. The regular bypass condenser must be em-

ployed with this resistance as well as with all other bias resistances.

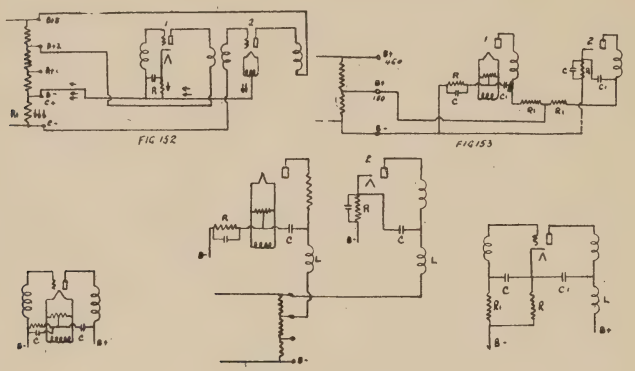
In the event that a cathode type of tube is employed with such method of securing the grid bias, the cathode terminates at the B minus instead of the heater filament transformer center tap.

More than two audio tubes connected in any fashion should never be supplied with grid bias voltage by one resistance. While it is true that the type of vacuum tube used governs the grid bias applied, the exact bias or the means of securing the bias is in no way controlled by the form of audio frequency amplification. If the voltage rating of a certain tube is of a certain value, that value is applicable no matter what the form of coupling or element in the plate circuit. However, nothing is gained by employing an excessive bias upon a vacuum tube, even when the plate voltage is of the value suitable for that bias. By this we mean that the bias voltage applied to a tube should be in accordance with the plate and filament voltage but it should also be governed by the signal voltage to be applied. The reason for this is that each increase in grid bias increases the plate impedance of a vacuum tube and influences transfer of energy to the load connected into the plate circuit.

GRID, FILAMENT AND PLATE CIRCUITS

While it is true that sources of operating potential are designed to coördinate with amplifier circuits, the respective plate voltages available at various sources are not always the exact value required for a certain specific installation. What method is employed to reduce the voltage required for a certain specific installation. What method is employed to reduce the voltage so that it shall conform with the tube requirement. The most logical is the use of a resistance in series with the source of potential and tube circuit, and this is done as in Fig. 153. Picture for a moment an eliminator source of plate potential equipped to supply two output potentials, 450 as the maximum and 180 volts for some of the tubes in the system. It is desired to use this system with an amplifier consisting of three tubes as shown. We omit the grid circuits since they are of no consequence at this time. The resistance R1 is used to decrease the voltage required for tubes 1 and 2 to the proper value since that available at the 180 volts tap of the B eliminator is excessive. The resistance R is employed to produce the grid bias for the tubes. The first operates in conjunction with a filament type of tube, whereas the second operates in conjunction with a cathode type of amplifier tube. Each resistance is bypassed with a condenser. Since it is necessary to keep the A.C. signal current variations in the plate circuit out of the eliminator or source of plate potential, a bypass condenser is necessary in addition to each plate voltage reducing resistance. These condensers are designated as C1 and offer a path of low impedance to the flow of the signal currents, bypassing them to the filament or cathode circuit, whichever it may be and obviating passage into and through the source of plate potential. An open in one of these condensers will upset the balance in the various circuits, cause regeneration or inter-

action between the circuits. If sufficient energy from one tube plate circuit finds its way into the succeeding tube circuit, the amplifier will howl. If this energy is not sufficient to cause continuous howling, of either low or high pitch, it will alter the characteristics of the amplifier changing its frequency response



FIGS. 152—156

curve, by causing excessive amplification on low or high notes, depending upon the design of the system.

Such bypass condensers find application without voltage reducing resistances. The path of the signal current should be solely in the plate circuit and in the grid circuit, hence bypass condensers are provided whereby the circuits are limited to the grid filament and the plate filament, as shown in Fig. 154. We show chokes in the grid and plate circuits, but this data applies equally well to resistances. These condensers offer paths of low impedance in the grid and plate circuit, back to the filament.

Another method of minimizing interaction in amplifiers is to locate a filter circuit in each plate lead in the form of an audio frequency choke and a condenser, as shown in Fig. 155. These chokes are designated as L and operate in conjunction with condensers C. The chokes L block the passage of signal currents into the B supply and the condensers C offer the path of low impedance into the filament or cathode circuit. The use

of such combinations is not limited to the systems shown. The resistance located in the plate circuit of tube 1 is the plate coupling resistance of a coupled stage. The resistance R is the grid bias unit bypassed by their associated capacities. Such audio filter systems may be employed with all types of amplifiers and the inductances are frequently quoted as reactors, audio frequency chokes, retard coils, etc. Their function is not to govern the magnitude of energy transfer between the tube and its load, but to act upon the signal currents and force them into their predetermined and allotted paths. The design of the reactors or audio frequency chokes is not limited to either iron core or air core windings, hence we show some with iron cores and others with air cores.

Filters of this nature find application in all amplifier systems regardless of the nature of the power supply, be it batteries, B eliminator or generator. Neither is this location limited to plate circuit.

Filtering in the grid circuits to minimize regeneration and interaction is accomplished by means of resistances. Experimental work of this nature has shown the importance of the elements to be discussed. In many installations of high power

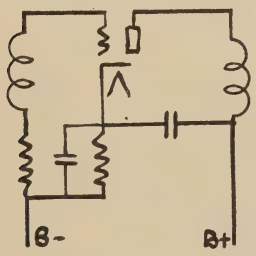


FIG. 157

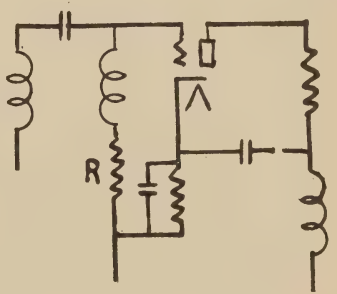


FIG. 157A

they proved to be the method of securing the anticipate low frequency response based upon the known high quality design of the coupling units. These resistance units are located in the grid circuit as shown in Fig. 146. At the first glance one would imagine that the resistance R1 interfered with the grid bias.

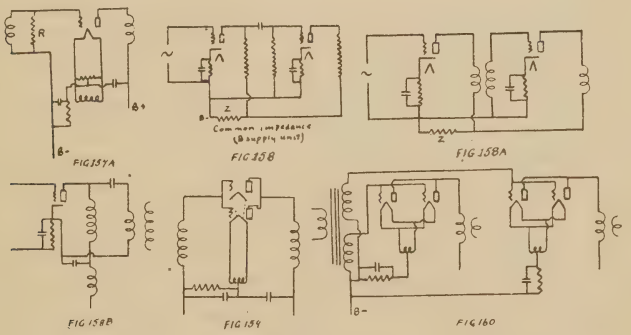
Also with the performance of the grid circuit. Such is not the case as will be evident upon closer examination. Since grid current is supposed to be absent in the grid circuit, voltage drop across R1 is absent. The grid bias is secured by means of the resistance R in the cathode circuit of the tube. If the tube is of the filament type, then the junction of C and R is at the midtap of the filament circuit. The path of low impedance in the grid circuit is secured by means of the condenser C. This capacity approximates about 1 mfd and the resistance R1 about 500,000 ohms. Its function is to minimize regeneration in the circuit and thus maintain the desired stability.

Another system provides for the insertion of a resistance between the grid coupling unit and the grid of the tube. This is usually limited to transformer systems, although in some instances, it finds application with impedance coupled audio amplifiers. Both systems are shown in Figs. 157 and 157A. They are designated as R in each circuit.

Still another method is to employ a resistance in shunt with the secondary of the audio frequency transformer, as in Fig. 157B. The resistance R reduces the amplification in the system and at the same time changes the characteristic of the transformer so that it conforms better to the requirements of the amplifier. The magnitude of this resistor varies between 200,000 ohms and 500,000 ohms.

Thus we note the use of condensers, inductances and resistance for purposes other than to store electricity, remove hum from eliminators and to cause voltage drop from one value to another required value. Too much stress cannot be placed upon the need for correct filtering and limitation of the paths for the signal current. However, interaction may also be due to conditions other than lack of filtering of the nature mentioned. Incidentally the expression "common impedance" is frequently mentioned in connection with amplifier systems. This term is employed to denote an impedance which may be common to the plate circuits of the amplifier or the grid circuits of the amplifier or both. Such a common impedance is the source of plate and grid potential. It may be batteries, B eliminator or generator. Time and again, excessive regenera-

tion takes place with battery supply. The difficulty is due to coupling of more than one circuit via this battery and the flow of the currents in these circuits through the impedance of the battery. In the majority of cases new batteries present low impedance values so that the voltage developed across the impedance is low. However, deterioration increases the impedance and the drop is consequently increased. When it reaches sufficient magnitude the amplifier commences to perform in an unstable manner and sometimes howls at an audible frequency. Examples of a common impedance are shown in Figs. 158 and 158A. The function of the various resistances, chokes and condensers shown in Figs. 153 to 157B inclusive is to detour the signal currents so that the current through Z, is very small. Assuming the impedance to be the A.C. resistance of a complete B eliminator system, it is obvious when considering that the B supply voltage divider is common to all the plate circuits, that a high value of output tank condenser is required in order to provide a low impedance which is common to all the circuits. This is of importance in addition to regular filtering as shown.



FIGS. 157A—160

Perhaps a word or two about resistance coupled systems will not be amiss. Such a stage is illustrated in Fig. 158. Neglect the common impedance Z at this time. Frequent mention is made that "blocking" of the amplifier occurs. By this is meant an intermittent "motorboating" sound of varying rapidity.

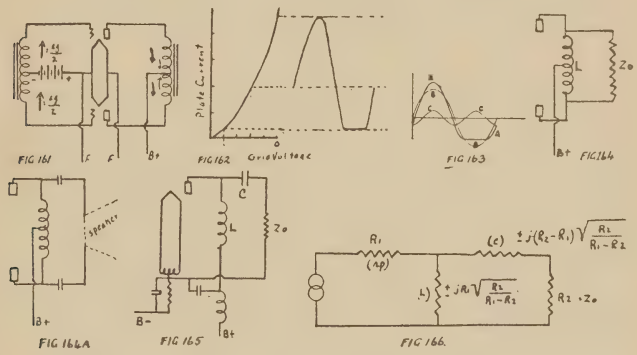
Sometimes it is very slow, once a second or once every few seconds. The solution is found in the values of the grid leak and the isolating capacity, or the adjustment of the time constant of the circuit consisting of the isolating or coupling capacity, whichever way it is known, and the grid leak. The time constant of the circuit is the product of the capacity in farads and the resistance in ohms. If the time constant is large, stability is secured. However the time constant may be varied in two ways, by changing the value of the condenser and also by changing the value of the grid leak. If the condenser is changed, its reactance at low frequencies may be excessive and cause a loss of amplification on the lower frequencies. This is undesired. However, if the grid leak resistance is reduced, the amplification does not suffer to a very great extent although investigation shows that a loss is entertained at the higher audio frequencies. However, a compromise between the regular type of filter located in the grid circuit and the change in the grid leak will undoubtedly provide the desired results. A time constant of between .02 and .03 seconds will be found satisfactory. The former consists of a .01 mfd. condenser and a 2 meg. grid leak. These values should not be construed as standard because it may be possible to increase the value of the coupling capacity to a much higher level without trouble. The exact condition depends upon the design of the complete amplifier.

Generally speaking trouble from excessive regeneration is more pronounced in high power amplifiers than in amplifiers of lower amplification rating. This is particularly true when the amplifiers is designed so that it will perform well on low frequencies. The better the low frequency response the greater the possibility of excessive regeneration, interaction between tubes, howling, etc., unless special precautions are taken to prevent such conditions.

Parallel Feed

All plate circuit arrangements do not provide for flow of the plate current through the transformer winding. The use of

alloy cores for high quality transformers makes imperative minimization of the magnitude of plate current in the transformer and in many instances this direct current is passed through a separate circuit and isolated from the transformer primary winding. Such an arrangement is shown in Fig. 158B.



FIGS. 161—166

Several advantages accrue from such an arrangement. First in better performance of the transformer. Second elimination of magnetization of the core because the D.C. does not flow through the core. Third in minimization of regeneration. Such systems are in use in connection with push-pull systems, wherever the tube plate current is not wanted in the coupling unit.

PARALLEL PUSH-PULL AND OUTPUT CIRCUITS

VACUUM tubes employed for amplification are not limited to simple cascade systems as shown, wherein one tube is employed in each stage. It is possible to connect tubes in parallel, so that they operate in tandem. Two effects are realized from such an arrangement, shown in Fig. 159. The first is increased output and the second is a lower total tube impedance.

With respect to the utility of such tube arrangements, it is necessary to mention that the tubes must be alike in electrical constants and characteristics, since they are being operated at like values of plate, filament and grid potential. This means that their amplification constant and plate impedance values should be alike. If not, the desired condition will not be obtained.

As to the benefits derived, experiments made upon approximately 200 tubes of various kinds, average and specially selected with respect to uniformity of constants showed a gain of about 30% over the output of a single tube. That is to say, the output power of two tubes in parallel was about 30% greater than that of a single tube of identical type. Theoretically the power output should double because the plate resistance is halved, yet such is not the case. The only advantage secured from the combination is that the total tube plate impedance is equal to half of the tube plate impedance of one tube, thus affording a means of securing better power transfer at the low frequencies from any one value of load impedance.

Paralleling tubes does not allow greater signal input or any changes in the input circuit of the tube. The grid bias required for a single tube is still the same for the system. The only difference is that the value of the grid bias resistance is reduced because the value of the plate current flowing through the

resistance has been doubled. Incidentally it is possible to parallel tubes in combinations of 2 to at least 4 or 5 pairs, if separate plate and grid bias sources are applied to each pair. Such an arrangement is shown in Fig. 160, where the secondary of the audio transformer which feeds the output stages is split in two, feeding two pairs or two tubes in parallel. As is evident two separate output transformers are also employed, one for each bank of tubes.

Push-Pull Systems

Quite a great deal of the satisfactory operation available with the modern amplifier is due to the fact that the vacuum tubes in the system may be connected in a certain fashion which eliminates a good deal of the distortion which would otherwise be present. Further, this system eliminates the troubles which would otherwise be present due to certain design conditions and which are not satisfactory with simple single tube cascaded stages. We refer to the push-pull system of connecting vacuum tubes.

While the parallel combination is resorted to in output stages only, the push-pull amplifier finds application in all stages of the amplifier, and the parallel push-pull system is popular as the output stage in many complete "talkie" systems.

The best explanation of a push-pull amplifier is that it is a balanced amplifier or a symmetrical amplifier. The function of the circuit arrangement is to eliminate distortion of the wave form of a signal, in other words, to eliminate distortion in an amplifier. The utility of the system is based upon an inherent characteristic of the vacuum tube, namely that the relation between the grid voltage and the plate current for any one tube does not produce a symmetrical characteristic.

Consider the transformer coupled push-pull system shown in Fig. 161. The difference between this and the conventional transformer coupled arrangement is found in the design of the input and output units. The secondary of the input transformer is tapped in the center, each end terminating in the grid of one tube. In turn each end terminates at the end of a center-

tapped winding in the plate circuit. In effect the two tubes are connected in series and their plate impedances are therefore in series. Hence the total plate impedance of two tubes connected in parallel is equal to twice the plate impedance of either tube. As in the case of parallel tubes, the push-pull tubes must be identical in electrical constants for reasons to be shown later.

Now, as to the reason for the use of push-pull circuits, we find that the characteristic representing the variation in plate current with grid voltage approaches the parabolic. In the illustration shown the increase in plate current due to the grid voltage, around any point on the curve, is always greater than the decrease due to like grid voltage change. This of course is in contrast to the preceding curves where we showed the action of the grid voltage upon the plate current. The presence of a high impedance load in the plate circuit of a tube, as is the case in all the amplifying tubes of a system other than the output tubes tends to straighten the characteristic to the extent that it approaches symmetry, at least sufficiently so to say that amplification in the intermediate stages is sufficiently free from distortion. In the output stage, however, where power is to be delivered to a load, high impedances are not available, particularly with the dynamic speaker, wherein the impedance of the moving coil remains practically the same over the entire band of frequencies. With the cone type of speaker, the lower limit of load impedance in the D.C. resistance of the winding, approaching about 1,500 ohms at 40 cycles as the total impedance. Hence high impedances to straighten the characteristic are not available. It is therefore necessary to resort to some other means.

The curve in Fig. 162 indicates that a change of say 2 volts upon the grid will cause the plate current variation shown and the resultant plate current curve is lopsided. Such a condition results in the generation of an even harmonic of twice the input frequency. As a matter of information all tubes generate a large order of harmonics but the odd harmonics are of such small magnitude as to be entirely negligible. The second harmonic however, is very pronounced when distortion is present

and as a matter of fact, the general interpretation of "undistorted output" allows about 5% of the second harmonic to be present, on the assumption that this small percentage is not perceptible to the listener.

The effect of the lopsided curve is to introduce the second harmonic within the tube so that the plate current curve in Fig. 162 resolves into the combination curve in Fig. 163, where Bb is the alternating current output representing the fundamental frequency input and Cc is the second harmonic. The useful current is Bb. Now when a signal current is caused to flow through the primary of T1 in Fig. 161 a voltage is induced in the secondary. The direction of this voltage is as shown by the arrows. The total voltage is divided between the two tubes in the system and as is evident the phase of the voltage applied to the two grids differs by 180 degrees. The voltage on the grid is in one case Eg + eg ÷ 2 and in the other is Eg — eg ÷ 2.

If the passage of the plate current Aa of tube 1 through the output transformer primary resolves itself into the fundamental Bb and the harmonic Cc, the same condition takes place for the voltage applied to the grid of tube 2. However, since the fundamental voltage applied to the grids of tube 1 and 2 were 180 degrees out of phase, the fundamental plate currents will be out of phase and will flow through the output transformer primary in the direction of the large arrows associated with that unit. The harmonic frequencies, however, are in phase and flow as indicated by the small arrows. The currents represented by the large arrows are additive in the output winding, whereas the harmonics cancel out and do not appear in the output secondary winding, in which is developed a voltage due to the current in the primary. Thus the harmonics cancel out in the primary of the push-pull output winding. The effect of this condition is to increase the operating characteristic of the vacuum tubes and to overcome the lack of symmetry which causes the distortion associated with each individual tube.

Because of this action, it is possible to employ a low load impedance in the plate circuit without distortion. Generally speaking a low load impedance increases the curvature of the

average tube dynamic characteristic, increasing the magnitude of the second harmonic. The push-pull arrangement overcomes this defect. The fact that the harmonics balance out in the plate circuit of the push-pull stage allows less filtering in B supply systems and freedom from hum because of A.C. upon the filaments. Such hum voltages in the two tubes are in phase and cancel out in the output.

Push-pull provides an output when two tubes are used equal to about 40% greater than the sum of the individual output ratings of the two tubes. In other words, if each tube is rated at 4.6 watts and the required signal voltage is applied, the maximum undistorted power output assuming correct load conditions is about

$$2 \times 4.6 \times 1.4 = 12.88 \text{ watts}$$

Push-pull connection is not limited solely to the output stage. Many amplifiers employ tubes connected in this fashion in all of the stages and some even use 4 to 6 tubes connected in parallel push-pull in the output.

Several interesting facts may be said about such push-pull systems. The first important requisite is that the tubes be of like character, that is of like electrical characteristics. The second is uniform D.C. plate current in each half of the output transformer primary. The presence of direct current in any iron core winding, particularly an audio frequency transformer tends to reduce the operating efficiency of the unit. The use of a split winding allows a possible means of completely nullifying the action of direct current in the windings, thus augmenting the operating efficiency of the unit. In the first place, direct current through the winding lowers the inductance, hence the reactance. In the second place, the effect of direct current flow through a winding employing an alloy core such as that in use today, tends to interfere with the action of the core, causing a reduction in the effective impedance of the winding and sometimes damaging the core entirely. In the third place a given current in the primary produces the same effect as another current in the secondary as much larger than the primary current as the square root of the ratio of the primary impedance

to the secondary impedance. Such currents are detrimental to transformer performance.

Since the two halves of the transformer primary are supposed to be alike and since the two tubes in the system are supposed to be alike and the fact that the D.C. current passed into the primary of the transformer diverges into two opposite directions, the net effect upon the core will be zero, providing that the current in one half is equal to the current in the other half. Thus it is possible to eliminate the magnetizing effect of the direct current upon the core.

Output Systems

It is not sufficient to amplify sound in electrical form to the correct intensity. It is necessary to transfer the power available in the output tube to the proper sound reproducing equipment. In other words it is necessary to transfer the electrical power available in the output tubes to the loud speakers, in which units the electrical energy produces mechanical motion and converts electricity into sound.

Output systems are of several types but before entering upon the discussion it is necessary to mention that the action is a transfer of power, of electrical power. The transfer of power in an output system allied with vacuum tubes can take place under two conditions. First maximum power transfer and second, maximum undistorted power transfer. The two are distinctly different. The former involves a good deal of distortion, whereas the latter involves maximum power consistent with minimum distortion. Fortunately the actual difference between the two is not very great.

The important item in an output system is that the correct impedance relation be maintained, and this is that the load impedance must be equal to twice the tube impedance. However, because of other impedance relations found in output circuits allied with speakers it is necessary to mention that the relation $Zo = 2rp$ applies only to the vacuum tube.

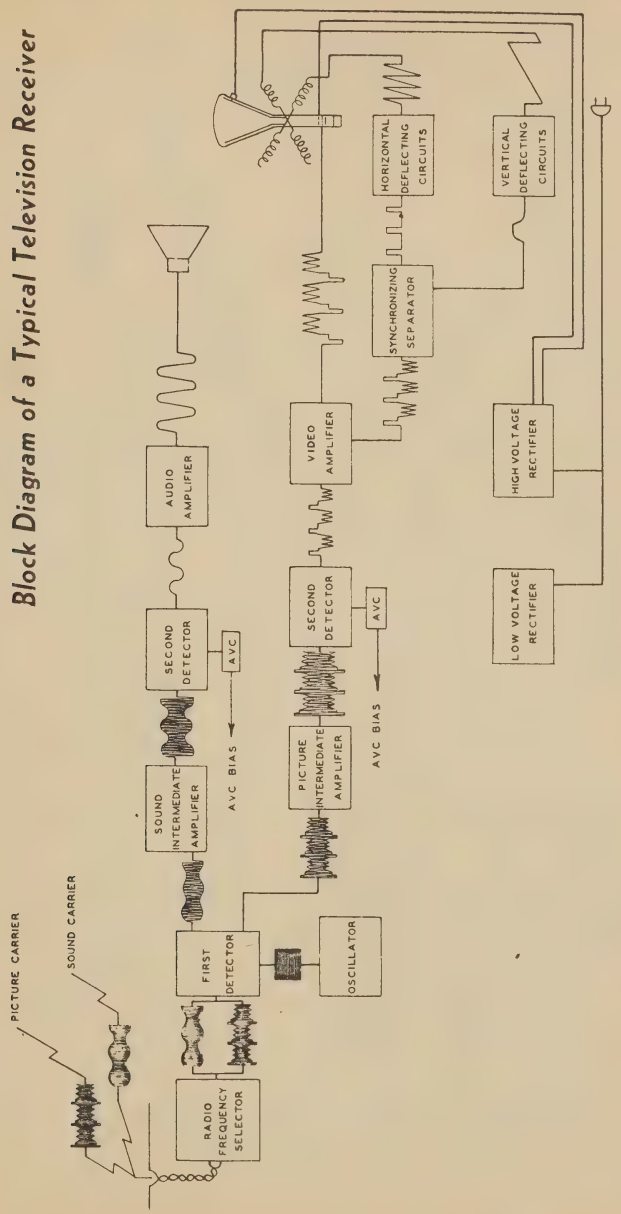
Several different methods of transferring power available in a vacuum tube (output tube) to a load are in use today. The

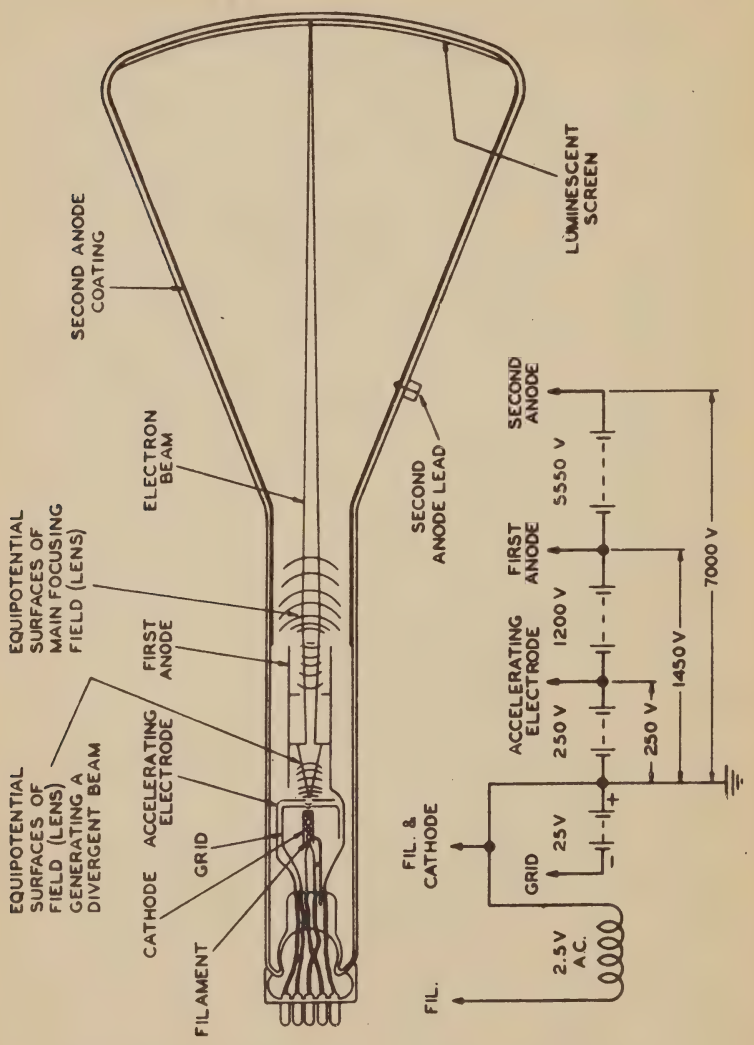
first entails a single center tapped choke employed in a push-pull system as shown in Fig. 164. Since the D.C. plate currents flowing in the two halves of L are equal and opposite, the voltage drop across the extremities of L is zero. This means that the load impedance may be connected across L without D.C. flowing through Zo. In an arrangement of this type Zo is the load impedance and the function of L is to allow the passage of the tube plate currents and to retard the flow of A.C. so that the maximum is impressed across Zo. Such systems are employed in connection with cone (electro-magnetic) speakers. Since Zo is the load, its impedance must be equal to 2rp. In the case cited, where rp of tube 1 is equal to rp of tube two, the impedance of Zo must be equal to 4rp. The frequency at which this impedance value is determined is a matter up to the design of the tube system. We are referring to the impedance of Zo, since the impedance of the tubes remains constant at all frequencies.

Another output system is shown in Fig. 164A. Here two fixed condensers are in series with each lead of the speaker or speakers as the case may be. However, the impedance of the load remains that of Zo because the usual values of capacity are such as to possess small values of reactance at even the lowest frequency. Now, it is possible that more than one speaker is to be employed with such a system. This does not alter the impedance relation between rp and Zo. If for example the impedance required for Zo is 8,000 ohms and the impedance of the speakers is 4,000 ohms each, two may be connected in series and the combination employed as Zo.

If the output tube is a single tube, a choke condenser output is employed as in Fig. 165. The impedance Zo, the loud speaker still bears the relation Zo = 2rp.

Block Diagram of a Typical Television Receiver





The Kinescope and Voltage Supply System

BASIC TELEVISION

Television requires us to send pictures by means of electricity. Pictures are made up of light and darkness. We should have some device which will change light into electricity so that we can send it over wires or by radio. Fortunately, a number of different devices will do this for us, one of them being the photoelectric cell, with which all projectionists are more or less familiar.

The photoelectric cell is a special kind of electronic tube in which light will cause an electric current to flow. If there is no light, there will be no current, but when there is light on the photoelectric cell the current will increase as the light is made brighter. Even with a very bright light, the amount of current is exceedingly small, but this is no hindrance because we can amplify the current of the photoelectric cell and obtain as much current as we require. If we amplify the current sufficiently we can cause it to light an electric lamp and make the lamp's brilliancy proportional to the light which shines on the photoelectric cell.

An arrangement was proposed many years ago using photoelectric cells, amplifiers and lamps to send pictures by means of wires. Basically it was simple. You simply stacked up numerous photoelectric cells in a bank and connected each one through an amplifier to a corresponding lamp of similar bank. If you projected a picture on the bank of photoelectric cells, each lamp would light according to the amount of illumination on its photoelectric cell and would produce a crude picture made up of lighted or darkened lamps, something like an electric sign.

In fact, this method has been used for showing animated cartoons on electric signs.

There are two drawbacks to this idea, however, if we want to send pictures any distance. In the first place, you have to use a great many lamps to get any degree of detail. The problem is akin to that of producing pictures in newspapers, where the printed picture is made up of tiny black and white dots. If the dots are coarse, the picture shows little detail but if there are many small dots, we can see a great deal which was lost in the coarser "screen." The reason is easy to understand. Each dot can only represent shades from black to white, it can show no configuration and all details smaller than the dot are lost. In a photograph of a face, if the dots were coarse enough so that one dot covered an eye, all details of the pupil, iris and white would be lost, the eye would show only as a round spot. In the same way, to get a good picture with an electric sign, we require an enormous number of lamps and their corresponding electric cells, amplifiers and connecting wires.

To send a picture having the same amount of detail as a very coarse newspaper photograph of two by three inches, ten thousand lamps, ten thousand photo-electric cells and at least the same number of wires would be required. Consequently, this method is not a very practical one for television.

SENDING PICTURES A DOT AT A TIME

The arrangement we have just explained will send a picture all at once. Every part of the image is transmitted simultaneously and reproduced at the same time. It is this all-at-once transmission which introduces the complications. It seems natural to consider sending sections of the picture, one after the other, natural because we do this ourselves when we read. If we look at a page in a book, we get no intelligence from it until we start to scan it, one word at a time, along the lines of print. As our eyes move, we perceive words, one after the

other, until we reach the end of the line when our vision jumps quickly to the line below. When we have reached the last line of the page, we start in again at the top of the next page. In this way we have scanned the pages line by line.

The same method can be used for sending pictures by electricity. The sensitive spot of the photoelectric cell can be moved across the field of the picture, one spot at a time, line by line, until the whole view has been covered. If the reproducing lamp is moved in the same way, the picture will be built up, one spot at a time, and line by line.

Facsimile pictures are transmitted in this manner by radio or by wire line. The impulses operate some device at the receiving end which prints the picture dot by dot. It may take several minutes to scan the picture and it is possible to watch the reproducer build it up, line by line.

The facsimile process enables us to transmit still pictures and we can take our time about sending them, using as long or as short an interval for building up of the printed image as we feel is desirable for economic reasons. But in the case of television, we want to send pictures giving the illusion of motion. To do this we must send many complete pictures each second so that action is smooth and in no way jerky. But we also wish to create the illusion of viewing the picture continuously rather than seeing a series of separate images. To do this we utilize the "carry-over" of vision. It is the nature of our eyes to retain a visual impression for a brief interval after the light rays have ceased to strike the eye. If we project a number of separate images with short intervals interspersed, the retentive ability of the eye "carries over" the preceding image until the next one is viewed and we apparently see a continuous view. This of course, is already well understood by projectionists, who know that motion pictures are only possible because of this "persistence of vision." About 16 pictures or more must be

shown each second to retain the impression of uninterrupted vision. Thus in the case of television, we have to build up each image of small dots and to provide at lease 16 complete images each second.

The fundamental method of transmitting pictures by television, therefore, consists of analyzing the picture into elements, sending their equivalent light values by electrical means, reconverting them into light elements and reassembling the picture again. The whole process must be carried out so rapidly that the eye sees a continuous view. We need only a single photoelectric cell type of device, one light-reproducing device and a single pair of interconnecting wires or the equivalent, a radio circuit.

PICTURE DETAIL

If television had preceded motion pictures, there would be no direct standard of comparison for the quality of reproduction. But the public is now accustomed to seeing very excellent detail on the motion picture screen. Television images are expected to be comparable. Let us assume that we need picture quality of the same order as that of a 16 mm amateur movie film. For this condition we need about 400 to 500 lines and since the picture is slightly wider than it is high the equivalent number of spots, side by side in a horizontal direction, is around 600.

It is a requisite that the television picture "tell the story" and that the detail be sufficient to enable the observer to follow action readily. Numerous observations have indicated that a picture composed of about 450 lines meet this requirement. It is undoubtedly true that the additional detail resulting from the use of a greater number of lines would improve the picture. But an increase in the number of lines can be attained only by a corresponding increase in technical difficulties and greater cost for transmitting and receiving apparatus.

Furthermore, a picture of about 450 lines contains

detail which approaches the resolving power of the eye for ordinary viewing distances. The smallest detail which can be seen is measured by the "acuity" or the angle from the eye to two points so close together that they can just be distinguished as separate. For motion pictures, this angle is approximately two feet. If a picture is viewed from a distance of four times its height, it is possible to perceive only about 440 lines. Theoretically at least, if we do not approach closer than this distance from the picture (40" for a 12" receiver) we will not notice any lack of detail. In Europe, pictures composed of 405 and 441 lines are in general use. In the United States, the latter value has been regarded as satisfactory.

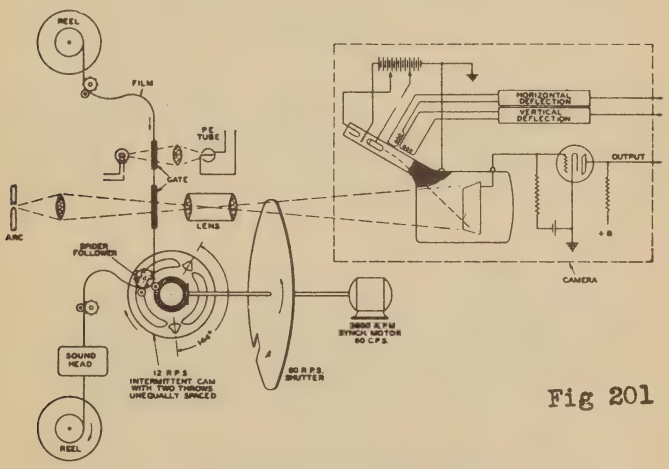
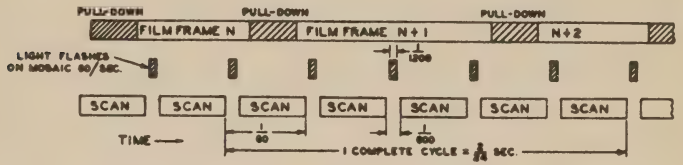


Fig 201

Schematic of film projector for Iconoscope camera.

Thus the total number of spots which have to be sent for each frame of the picture is around 260,000. Since we must transmit each picture in less than 1/16 second, the beams which scan the picture and reproduce it must move at an enormous rate of speed. Actually, for reasons to be discussed later, the picture must be transmitted in less than 1/30 second.

If we attempt to provide rotational methods for moving the scanning and reproducing beams at the required velocity, we face great difficulty. The mechanical elements must rotate at fearsome speeds, bearings wear out rapidly and the centrifugal force produced by



Preferred sequence of events in film transmission by Iconoscope.

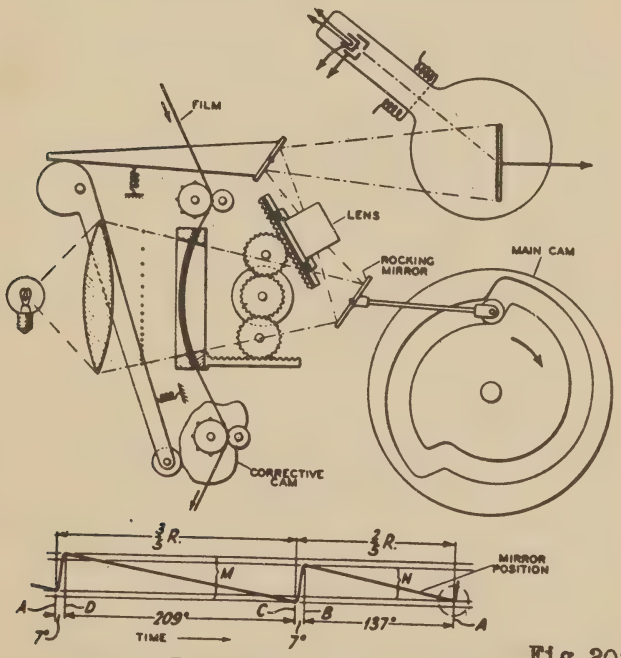
Fig 202

the rapid rotation may be a source of danger if precautions are not taken. Consequently, when methods were evolved for moving beams of electrons instead of masses of metal, television took on a more practical aspect.

Diagrammatic illustration of progressive scanning and interlaced scanning.

But there is another problem connected with picture detail. That is the band of frequencies which must be transmitted. To transmit music, we must handle the frequencies corresponding to tones to which the ear is sensitive, namely from 30 to about 15,000 cycles. No improvement is realized by handling a wider band because the ear would not hear the extended range.

In television, the more detail we wish to transmit, the greater the band of frequencies which is required. In the case of a picture of 441 lines, with about 600 dots along the line, time taken to traverse one line will be slightly under 1/13,000 second and the time to scan the width of two spots along a line (corresponding to one cycle) is about 1/4,000,000 second. Since the frequencies which must be transmitted correspond to the



Experimental rocking mirror projector. Fig 203

rapidity of change of the impulses, the highest frequencies produced in such a picture will be in the order of 4,000,000 cycles. This is a value of band width over 250 times as great as is needed for sound transmission. The need for wide frequency bands causes further problems to be encountered.

WIDE BAND TRANSMISSION

It is customary to refer to the electrical impulses corresponding to sound as "audio" frequencies. In the same way, the bands of impulses generated in television are called "video" frequencies. For a moderately good picture a band of from 30 to 4,000,000 cycles is needed with somewhat more horizontal than vertical detail.

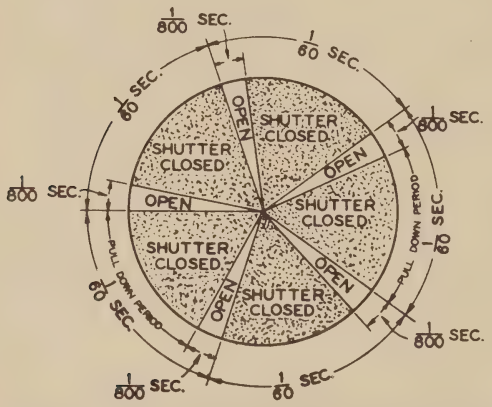


DIAGRAM OF ONE COMPLETE CYCLE OF OPERATION OF TELEVISION FILM PROJECTOR
ENTIRE CIRCLE IS $\frac{1}{12}$ SECOND

Diagram illustrating the 3:2 ratio of pull-down periods in a special television film projector.

It is difficult to build amplifiers capable of handling video bands as wide as this and to maintain uniform response to all frequencies. Special consideration must be given to circuits and often special electronic tubes are needed. Even ordinary pairs of wires are incapable of carrying the full band, and special types of lines have to be used, for distances of more than a few feet.

For television radio transmission, it is necessary to modulate a transmitter having a fixed carrier frequency wth impulses varying in frequency from a low value up to several million cycles. It is a requisite that the carrier being modulated operate on a higher frequency than the highest video frequency to be employed. Trying to modulate a transmitter operating on 1,000 kc (1,000,000 cycles) with a video frequency of 4,000 kc (4,000,000 cycles) would be like trying to divide a group of 1,000 matches into piles of 4,000 each.

It is thus necessary to employ a high carrier frequency for the television transmitter and, in practice, carrier frequencies of from about 45 megacycles to 200 megacycles (6.8 meters to 1.5 meters wavelength) have been used. Because of the extent of the sidebands, the televsion channels is much wider than would be required for a sound broadcasting station. In fact, the frequency spectrum for the entire 110 channels of the broadcasting band would fit easily within one television channel.

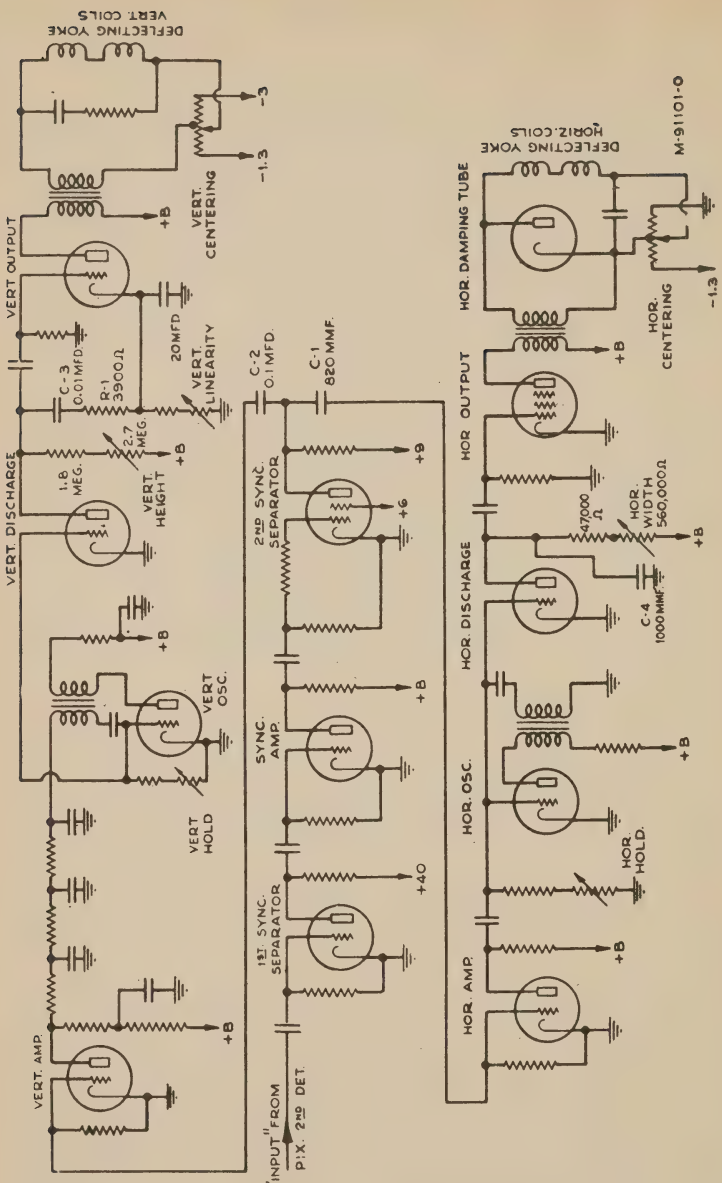
THE ICONOSCOPE

The initial process in television transmission consists of breaking up the picture into small spots and obtaining a small current of electricity proportional to the brightness of each individual spot. This current can be amplified and transmitted to distant points.

The Iconoscope serves the dual purpose of analyzing the picture into spots and producing the electric currents for each picture element.

It does this in a very satisfactory way, without moving parts, as far as can be seen, and it produces more current than previous devices could secure.

Basically, the Iconoscope is a vacuum tube in which are mounted a mosaic and an electron gun. The mosaic is a sheet of mica a few inches square on which have been deposited millions of tiny particles of silver sensitized with caesium. Each particle is insulated from its



Synchronizing and Deflecting Circuits

neighbor by the mica between. On the other side of the mica plate is a metallic coating. The picture is focussed on the front of the mosaic by a suitable lens.

Each tiny piece of silver is a miniature photocell and if it chances to be in a part of the image which is light, it will lose electrons and acquire a slightly positive charge.

On the other hand, its charge will be unchanged if it lies in a dark region. Thus there is built up on the mosaic a pattern of electric charges in accord with the light and shade of the image.

At the other end of the bulb is the electron gun. This is a device for producing a sharply focussed ray of electrons directed toward the mosaic. The beam strikes the mosaic in a small invisible spot. The beam is made up of negatively charged particles or electrons in motion and hence is a current of electricity.

Now if a caesiated globule has been exposed to the light in a white portion of the picture, it has lost electrons and its positive charge has been increased. When the electron beam strikes this globule it supplies back the electrons which light had caused to be emitted and thus restores the charge to the original value.

The beam contains many more electrons than are required to restore any individual globule and the excess electrons pass to a collector electrode on the inside of the glass bulb. When the charge of the group of globules on which the beam impinges is being restored, the charge on the metallic conductor at the rear of the mica plate is also changed by capacity to the group of particles.

We may think of the cluster of globules as forming tiny condensers, slowly charged by the action of the light and suddenly discharged by the sweeping beam. One plate of all the small condensers is common (the metallic coating) and a current flows from this terminal through a resistance, thus developing a voltage which

is proportional to the light on the spot which is being scanned.

The electron beam must be made to sweep across the mosaic in lines and at the same time to move slowly from top to bottom. It must jump rapidly from the end of one line to the start of the next and from the bottom to the top. Two pairs of electro-magnets move the beam. One of these pairs serves to produce lateral motion, the other vertical motion. Because the beam has practically no inertia, it can be moved at high speeds to scan the mosaic. The Iconoscope is therefore a special sort of photoelectric cell which scans the images as well as converting it into electrical values.

KINESCOPES

We have reduced a picture into electrical terms for purposes of transmission and, at the television receiver we wish to convert the electrical values back into light again. This is the function of the other vacuum tube called the Kinescope.

This tube contains an electron gun producing a sharp beam of electrons (or a cathode ray) and also a grid for controlling the intensity of the beam. On this grid is imposed a voltage proportional to the output current of the Iconoscope. If the spot scanned in the Iconoscope is bright, the grid will permit many electrons to flow, on the other hand, if the spot is dark, the electrons beam will dwindle. Thus the intensity of the beam is controlled in accordance with the light values.

The electron beam is quite invisible, but it is permitted to strike a fluorescent screen on the end of the tube. The spot of the fluorescent screen where the beam impinges glows in proportion to the beam intensity. The beam is also moved across the screen in lines, similarly to the Iconoscope beam, by means of electro-magnets, and as it does so, it paints a picture in spots of light.

This is the reproduced picture which we see in a

television receiver.

The color of image produced by the Kinescope is dependent upon the material used for the fluorescent screen.

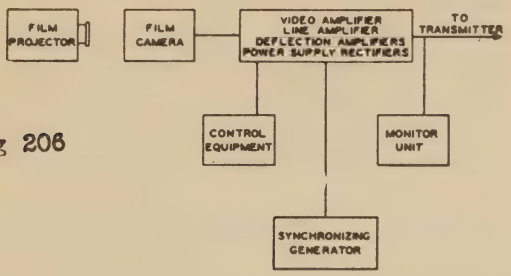


Fig 206

Essential elements of a television film transmission system.

Yellow or greenish pictures were often produced in television receivers because the screens producing these colors were particularly efficient and easier to construct. However, tubes are now available which give a more nearly black and white picture.

Since the screen is usually placed on one end of the tube, the larger the picture we desire, the bigger the tube must be. It is possible to protect the image from a small Kineoscope by optical means and to throw it on a screen, but a very brilliant Kinescope image is needed to obtain a satisfactory degree of illumination of the enlarged picture. Special projection Kinescopes have been made for the purpose of screen projected television. These tubes of course are much more expensive than those used in the ordinary receiver.

Kinescopes require a rather high second anode potential in the order of 6,000-8,000 volts for large tubes, although the current drain is small. Nevertheless, great care must be exercised in handling Kinescope circuits which are in operation.

SYNCHRONIZING

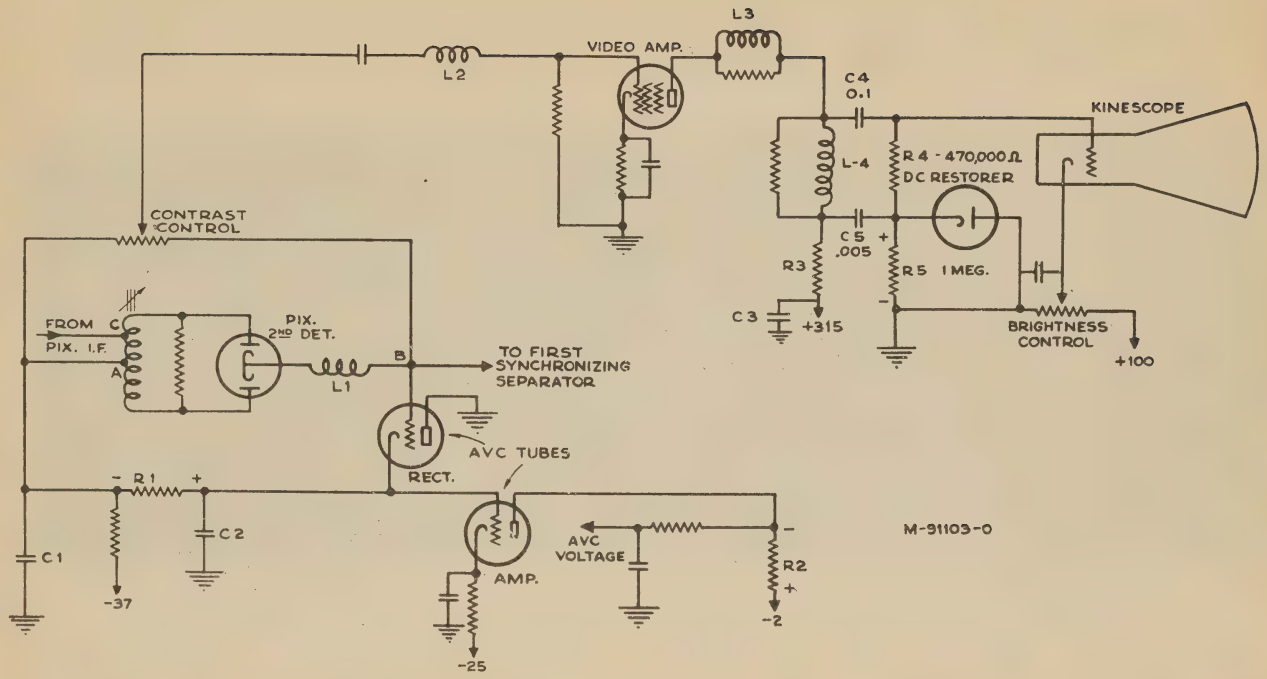
So far, at least, television seems to have a parallel in sound broadcasting. Iconoscopes seem the counterpart of microphones and Kinescopes reproduces pictures while the loudspeaker recreate sound.

But synchronizing equipment is required for television while it is lacking in a sound system. Pictures have physical dimensions whereas sound has not. The Kinescope beam must not only be modulated in intensity but must fall on the correct spot in the picture at all times.

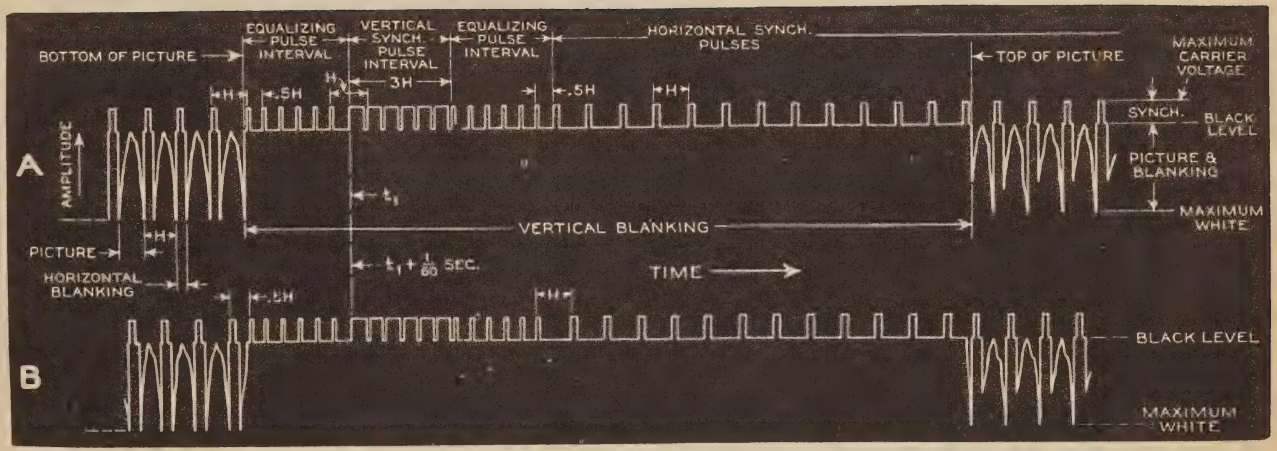
The function of synchronizing is to keep the Iconoscope and Kinescope beams in exact register. If they do not function together the picture will be either out of frame or badly mixed up, according to the degree of non-synchronization. It is necessary to generate impulses at the studios which will act on the Iconoscope magnets and which will be transmitted to the receiver to actuate the Kinescope beam by means of its magnets. Two sets of impulses are produced, one for producing horizontal motion and the other vertical motion.

In addition, it is necessary to extinguish the trace which would be produced by the scanning and reproducing spots returning from the end of one line to the start of another line, as well as returning from the bottom to the top of the frames. "Blanking" pulses are produced and added to the video signal in the studio technical equipment. They are merely "black" signals which modulate the Kinescope beam to zero, thus making the return traces invisible.

These horizontal and vertical synchronizing and blanking pulses need to be sent out on the picture carrier. The synchronizing and blanking pulses are sent at the end of each line while the scanning spot is returning from the right to left. Fig 200 shows the signal and synchronizing impulses for a simplified 10-line system.



Picture Second Detector, Video Amplifier and D.C. Restorer


EQUALIZING PULSE INTERVAL
VERTICAL SYNCH. PULSE INTERVAL
EQUALIZING PULSE INTERVAL
HORIZONTAL SYNCH. PULSES
BOTTOM OF PICTURE
TOP OF PICTURE
MAXIMUM CARRIER VOLTAGE
SYNCH.
BLACK LEVEL
PICTURE & BLANKING
MAXIMUM WHITE
A
AMPLITUDE
H
.5H
3H
t_1
VERTICAL BLANKING
PICTURE
HORIZONTAL BLANKING
$t_1 + \frac{1}{60}$ SEC.
TIME
B
BLACK LEVEL
MAXIMUM WHITE

The rectangular block is the signal during each line from the black picture bar. The line blanking "pedestal" turns off the Kinescope beam while it is returning from right to left, and the small synchronizing impulse on top triggers off the lock oscillator in the receiver which controls the horizontal motion of the electron beam.

At the end of the picture frame, a different sort of pulse is sent. Fundamentally, a longer blanking wave is required because more time is used to return the beam from the bottom to top. Also the vertical synchronizing pulse is made longer so that it can be separated from the horizontal pulse and caused to start its own oscillator at the receiver. In practice, other pulses are added to keep the horizontal oscillators going during the vertical blanking.

The synchronizing generator must generate these wave forms and do it with a considerable degree of accuracy and stability.

STANDARDS

If all of the electric power companies had been able to furnish only one kind of power supply, all electric appliances would be equally useable everywhere. Instead, we find that some cities have direct current power supplies, some have alternating current supplies, and the frequency of the alternating current may be 25, 50 or 60 cycles. Fortunately, this is gradually being straightened out so that sooner or later, an electrical fan or other device can be plugged in anywhere, all equipment and apparatus being made for the same type of current supply.

In television there are many factors which need to be standardized if any television receiver is to be capable of receiving any television station. The Radio Manufacturers Association has issued a series of standards for television which makes receivers and transmitting equipment fit together.

The particular standards chosen have been selected for logical reasons. For instance, negative modulation is recommended. This means that when a bright portion of the picture is being sent, the power output of the transmitter is modulated downward. One reason which determined this choice is that receiving sets can easily be constructed to function with negative modulation to contain automatic volume control features whereas if positive modulation was to be used, it would be quite difficult to incorporate the automatic volume control circuit.

The standards provide for 30 frames per second, with interlacing, to assure freedom from flicker. They call for 441 lines to assure high definition pictures. The exact number of lines is determined by the requirements of interlacing and other allied factors. The "aspect ratio" or relation of width to height of the picture is the same as for sound motion pictures, 4 to 3.

It is desirable to reproduce the picture with the same overall illumination or light tone as exists in the original scene. One way to carry this out would be to use a system in which all of the circuits would respond to very low frequencies down to and including zero frequency or direct current. However, direct current amplifiers are expensive and difficult to handle from a technical standpoint. The system utilizes the more conventional alternating current amplifiers but keys the received picture to the proper overall shades of light or shadow by biasing the Kinescope grid in accordance with the height of the blanking impulses or pedestals. The amplitude of the pedestals can be adjusted at the station to a satisfactory level and the pedestal height then sets the average illumination of the picture in the receiver Kinescope. The picture signals produce a variation about this value in accordance with the detail of the scene being transmitted.

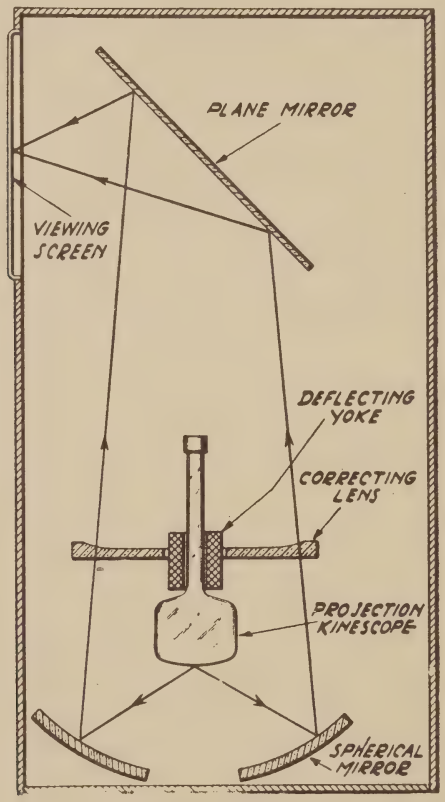
However, the direct current component is inserted in the signal in the transmitter. This is done by rectify-

ing some of the signal and allowing the height of the pedestals to control the carrier amplitude. A direct current modulated transmitter introduces some complications in design since the modulator must be directly connected to the modulated stage but makes up for this in increased efficiency. Its action resembles controlled carrier transmission—the carrier power will be high for generally dark pictures and low for light pictures. The carrier power is varied only for the period during which the picture signals are being transmitted. It is unaltered during the synchronizing and blanking periods.

The television transmitter differs in another respect from the conventional transmitters used for other services. It must be arranged to suppress part of one sideband. This is necessitated by the width of the channels which have been assigned for television and the width of the frequency bands which have to be fitted into each channel.

Each channel for a television station is 6 megacycles wide. We should like to transmit video frequencies up to about 4.5 megacycles to provide as good detail as possible. It will be obvious that if we use a conventional double sideband transmitter, a band of 9 megacycles will be needed and this will not fit into the 6 megacycle channel. Furthermore, there must be a relatively narrower space left for the sound transmitter. One way to retain the wide video band would be to cut off one sideband completely, but while it is relatively easy to produce single sideband voice transmission, it is difficult in the case of television to do this without spoiling the picture at the same time. Consequently it was proposed to partially filter one sideband. There remained one whole sideband, the carrier and part of the other sideband. It was then possible to move the picture carrier over and to use a wider video sideband of 4.5 megacycles in the same channel. But the receiving set would also have to be designed to reject one sideband or the response would not be uniform since the

output signal from the receiver would be proportional to the sum of the voltages from each sideband. With the partial filtering in the transmitter, and with a receiver capable of accepting both sidebands, the low fre-



Optical system of television projection receiver.

quency response would be high where there was voltage produced from two sidebands and would fall off at the higher frequencies where, due to filtering, only one sideband had been left.

Consequently, receivers must have a response which starts to cut off before the carrier frequency, and attenuates the carrier 50% in voltage (75% in power) and cuts off the other sideband almost completely. This produces a uniform response.

The partial sideband filtering process is accomplished in the RCA transmitter by a filter composed of concentric lines. The lines are tuned for the station frequency and left set in this position. The transmitter thus produces one full sideband, the full carrier amplitude, and a portion of the other sideband. In the receiver, the partial sideband is more completely removed and a filter with a sloping characteristic compensates for the tendency to produce greater low frequency response.

STUDIO EQUIPMENT

We have discussed the chain of apparatus which would be needed to produce a picture by television, but only the main points have been considered. In a television station, equipment will be required for switching, monitoring and controlling, as well as for secondary purposes in the television system. By tracing the requirements from the camera to the antenna a more comprehensive picture of the apparatus components will be obtained.

To begin with, the Iconoscope is needed to scan the scene being transmitted and to produce electrical pulses corresponding to the illumination on picture elements. The Iconoscope is ordinarily mounted in a camera with a lens system for focusing an image of the scene onto its mosaic The camera can be equipped with short-focus or long-focus lenses so that close-ups or wide angle shots may be taken. Means must be provided for focussing and for setting the view over the desired range of action. Usually an operator is required to manipulate the camera.

Apparatus is needed to convert the pulses from the synchronizing generator into sawtooth waves of cur-

rent which flow through the windings of the magnetic deflecting yoke. Usually a bridging amplifier drives the sawtooth deflection circuits, a portion of the latter apparatus being located in the camera to avoid distortion of the sawtooth waveform. A low level video preamplifier is preferably located in the camera in order to amplify the Iconoscope signal currents to such a level that they may be transmitted to associated rack equipment.

The sensitivity of the camera is roughly equivalent to that of a motion picture camera using orthochromatic film. This means that about the same amount of light is needed on the subject as would be used in the taking of motion pictures. Iconoscopes have been considerably improved in sensitivity and further advances will decrease the lighting requirements.

With present sensitivity, satisfactory pictures can be taken outdoors except late in the day or on very cloudy days.

The Camera is connected with the studio video apparatus by a heavy cable, about 1 3/8" in diameter, which contains all the interconnecting wires. Usually the power supplies for the Iconoscope and other tubes in the camera are located in the control room. At this point also is located the other apparatus including the amplifiers for the Iconoscope and the synchronizing generator, as well as the power supply units.

Due to certain electrical effects within the Iconoscope, various low frequency, synchronous, spurious signals are generated. In certain regions, for example at the center, the picture would be darker than normal if no correction were applied. "Shading" circuits have been devised and by properly adjusting the controls, uniformly reproduced pictures are obtained. The shading circuits require amplifiers which operate from the synchronizing generator and by adjusting the various knobs, one may lighten or darken any section of the frame and so compensate for uon-uniformity.

Since the electron beam does not strike the mosaic

at exactly right angles, the reproduced picture would tend to be slightly wedge-shaped were it not for the keystone correcting circuits which straighten out the sides.

It is necessary to introduce the proper blanking and synchronizing signals at the end of each line for operating receivers. The output of the Iconoscope does not usually contain a fully mixed signal and the impulses are inserted in the video chain of amplifiers.

Provision must also be made for observing the picture to check operation and to make adjustments. Hence, one or more picture monitors are needed to reproduce the image. These are similar to television receivers except that no radio chassis is included. This type of monitor can be used on the output of the studio system and is called a "synchronized" monitor because it operates from the final combined signal just as a receiver would. It may also be desirable to see the output of cameras before they are connected to the channel as a precaution for proper operation. In this case a "driven" monitor is used. This monitor operates from the uncombined signal and must have its deflecting circuits driven from the synchronizing generator.

A synchronizing monitor is roughly the equivalent of a loudspeaker operating from the output of a sound broadcasting studio, allowing us to hear what is broadcast. A driven monitor would be the equivalent to a loudspeaker with an amplifier which could be plugged across any microphone preamplifier to check its pickup.

It is necessary to adjust signal levels in television just as in sound broadcasting and also to set the height of blanking and synchronizing impulses. Instead of using a Volume Indicator, a small Cathode-ray Oscillograph is used to give a picture of the signals over a line, several lines, or over a whole frame.

In one respect, television possesses an operating advantage. It is difficult to work in a room with several loudspeakers going, but several picture monitors may

run simultaneously and we can look from one to the other and decide when to change cameras.

It may be desirable to use more than one studio camera so that we may shift quickly from a long shot to a close-up. In this case, one camera would be equipped with a short-focus lens and another with telephoto lens. By observing the monitors for each camera, the director in the control room may change points of view at the proper time. If several cameras are used, an operating console will probably be desirable to facilitate smooth performances. The sound equipment, which is similar to present broadcast apparatus is, of course, entirely separate, and if the installation employs several cameras, a sound control console will be required with separate control room operators for picture and sound.

DIRECT TRANSMISSION LIMITED

Because television stations operate on ultra high-frequency channels, the coverage is characteristic of this type of transmission. At broadcast frequencies, the longer waves provide local primary coverage by direct transmission and secondary coverage at greater distances from the station by reflection from the ionsphere; a series of ionized layers high above the earth which return the waves earthward. Hence, at great distances from the station it is often possible to find stronger signals than at a point closer by.

As wavelengths become shorter, long-distance transmission becomes better and better. At 15 megacycles (20 meter wavelength), propagation of waves over the sky path allows reliable communication for thousands of miles. But going still shorter in wavelength, we find that long-distance communication ceases except at intervals. A very short wave carrier provides only local coverage—the waves are no longer reflected downward by the ionsphere. But there are points along the wavelength scale where long-range transmission sometimes takes place and sometimes does not. The determination

of whether this will occur seems to be dependent upon sunspots.

Since the number of sunspots follows an 11-year cycle, so the "break" or critical frequency above which no long-distance transmission occurs, varies periodically every 11 years.

The caverage area is apt to be affected both by the station power, and antenna height. Because the waves are short there is less bending to take them over the curve of the horizon. Longer waves are refracted and there is no horizon point where they suddenly become weak. Ultra high-frequency waves, however, become more akin to light which does not ordinarily bend around solid objects. If we have a light on a high pole and if the terrain is unobstructed we will be able to see it as far as the horizon for the particular pole height. As we put the light higher, it can be observed further away. Obviously, if we climb above the surface of the earth we will see the light again, even though we may be beyond the horizon for the ground level. Thus the height of the receiving antenna as well as of the transmitting antenna affects the range.

The local coverage area, which is the only one which can, at present, be considered as a service area, is subject to the limitations of horizon as described before. While signals are heard beyond the horizon and while there is seldom a sharp line of demarcation as would be observed with light, the signal strength becomes weaker and weaker more rapidly than within the horizon. Therefore, from a practical standpoint the horizon may be considered as the limit of transmission until some method is found of providing for longer distance coverage.

But the signal becomes weaker as we go away from the station and the horizon will not be the limiting factor if the signal becomes so low that it will not operate a receiver before that point is reached. Thus low-powered stations will frequently not give satisfactory service as far as the horizon.

Television receivers require a few millivolts signal strength to operate. If the signal is less than this, the picture becomes "grainy" or takes on a "snowstorm" appearance. The cause of the interference is noise. In ideal locations, receivers will function at weaker signal level until the noise generated within their own tubes causes trouble. Generally, however, electrical noises created by the ignition system of automobiles, diathermy machines or electrical appliances used in the home or factory is the disturbing factor and the field strength of the station must be high enough to cover up their interference.

Thus in outlying areas, the limit of service will be determined, not only by the horizon but also by the noise level at the receiver. Increasing the power of the transmitter will not extend the horizon but will extend service within the horizon by riding over the interference. The physical horizon can be computed, but the noise level, as a factor affecting coverage, can only be checked by measuring it and plotting contours or by actual observation with receivers.

It will not be satisfactory to connect a television receiver to a few feet of antenna wire around the baseboard of a room. Good installations will be required, even close to the station. By putting up a good antenna structure, back from the streets, as high as possible, the electrical noise can be minimized.

The station can realize an effective increase in power by concentrating all of the radiation in a horizontal plane. In other words, the energy wastefully radiated upwards is directed towards a low angle where it is more useful. Transmitting antenna arrays for accomplishing this are not particularly difficult to install and they increase the coverage.

In broadcast practice, it has been customary to consider long antennas as being more efficient. Long antennas (within certain limits) are more efficient because the distribute the energy in a more nearly horizontal di-

rection and less radiation is sent up to be reflected back in the secondary coverage area. But even the longest broadcast antenna is not much over ½ wavelength long.

A ½ wavelength television antenna will be shorter than 12 feet for the same relative efficiency as a ½ wavelength broadcast antenna. Due to the different propagation characteristics of television wavelengths the height of the transmitting antenna, in contrast to its length, is a major determinant of the range and transmission. So, to extend its horizon, it should be placed as high as possible.

Ultra high frequencies are not subject to fading and experience no trouble from static, but they have a peculiarity—echoes. In centers of population, signals will often be picked up at the receiving antenna both directly from the station and also by reflection from a building or hill. Since the path length of both transmissions is not equal, each will tend to produce a picture and the two images will be slightly shifted. Such double images can usually be avoided by moving the receiving antenna a few feet or by using a reflector a few feet away to eliminate one signal.

From this it will be seen that television coverage is not a simple matter. However, the advantage of being able to use relatively short elements in an antenna array and to evolve unusually efficient systems, plus the absence of static and fading, help to compensate for the other difficulties which we encounter.

TELEVISION MOVIES

The diagram shown in **Fig 201** shows schematically an Iconoscope camera and a special projector adapted to project standard 24 frame-per-second film upon the Iconoscope mosaic in such a way as to generate television signals according to the Radio Manufacturers Association standards, namely, at 30 frames per second and 60 fields per second, interlaced.

The projector must flash a still picture upon the

mosaic every 1/60 second with each flash lasting less than 1/600 second. Since the film must run at a speed of 24 frames a second for proper reproduction of sound and motion, it is evident that each frame must be projected more than once to provide the required sixty flashes per second. Since sixty divided by 24 is $2\frac{1}{2}$, it would seem logical that each frame should be projected two and one-half times.

This is impracticable but a very satisfactory method is to project alternate frames of film two and three times each, respectively; for example, the even frames twice and the odd frames three times. **Fig 202** shows the various steps of projection and scanning in proper relative time on a horizontal time-scale. Since the light flashes are very brief, a relatively long (approximately 1/67 second) interval is available between flashes for the film pull-down.

However, if the full time available is used, the alternate pull-downs must occur at non-uniform intervals of 2/60 and 3/60 second, respectively. Note from this figure that the scanning or transmission times occur between adjacent light flashes so that the television picture signal is actually produced and transmitted during the periods when no optical image is present on the mosaic. During these periods an electrical image is present in the form of bound electrostatic charges on the tiny photosensitized silver globules comprising the mosaic. It is the act of neutralizing or, rather, equalizing these charges by the electron of the scanning beam that causes the useful signal current to flow from the conducting backcoating of the mosaic plate.

Referring again to **Fig 201** the film is drawn through an illuminated gate by an intermittent sprocket which in turn is driven by an intermittent cam and spider-follower of the early Powers projector type. The 3600-rpm special synchronous motor drives the cam at 12 revolutions per second through a suitable gear, thus pulling the film down 24 times per second, since the

cam has two "throws" instead of the customary one "throw." In order to pull the film at unequal intervals as required, the "throws" are located 144 degrees and 216 degrees apart. The film picture in the gate is projected upon the small photo-emissive mosaic of the Iconoscope by a standard projection lens. The light is chopped 60 times a second by a large rotating shutter, located near the lens. The shutter is accurately timed relative to the intermittent cam so that the film is al ways stationary when the light flashes occur.

The generator of synchronizing signals for the television deflecting system is synchronously controlled by the same 60-cycle power supply that drives the projector synchronous motor. The phase of this signal generator is adjusted so that the operator can make the short-duration light flashes fall safely within the 1/600 second intervals between the vertical scanning periods with some tolerance on each side for slight phase displacements such as are caused by small changes in the mechanical load on the projector or by voltage variations. This adjustment is very important, as any abrupt change in the illumination of the mosaic during the picture signal transmission time produces a spurious light streak across the received picture.

An ordinary 3600-rpm synchronous motor has two identical pole structures which can assume either polarity, and hence such a motor can lock into synchronism in either of two phase positions, depending upon starting conditions.

Two such lock-in positions are apart in time by one-half of a cycle of the power-supply frequency, which for a 60-cycle power system is 1/120 second. Inspection of the diagram **Fig 202** shows that displacing the light flashes 1/120 second with respect to the scanning periods would cause them to occur during, instead of between the scanning periods. The abrupt change in mosaic lighting caused by a flash during the scanning period would produce a serious streak across the middle of the picture as mentioned above. To prevent the frequent

locking-in of the motor in the wrong position, a special synchronous motor is used which includes an additional DC winding for fixing the polarity of the poles and thus determining the lock-in position with respect to the AC power supply.

The sound-head used is standard, since the mean speed of the film is 24 frames a second. It has been found that a suitable fly-wheel associated with the intermittent cam prevents any detectable deterioration of the reproduced sound due to the dissymmetry of the intermittent cam.

There is some evidence that the television picture transmitted by a system depending completely upon the storage principle might not be as satisfactory as one transmitted by a system in which the film image is projected upon the photoemissive mosaic either continuously or during the entire scanning period. It is natural therefore, that investigations of the latter type of system should have been made. So far the results obtained have not been wholly satisfactory and certainly have not been as good as those produced by the storage method.

An experimental projector using a continuously moving film and a rocking mirror for producing a stationary image, was built by RCA. A diagrammatic view of the projector is shown in **Fig 203**, the projector was however discarded for the type now used by RCA.

RAY FORREST
Television Announcer
-ORIGINATING AT NBC TELEVISION STUDIOS, RADIO CITY

LOWELL THOMAS
Theatre Television Handles The News and Interviews
ORIGINATING AT NBC TELEVISION STUDIOS, RADIO CITY

THEATRE TELEVISION
A Round Table Discussion
in which the following will participate:

GEORGE H. BULL, President, Empire and Saratoga Race Tracks; JOHN F. CASEY, Trustee, T. P. U. No. 1; T. F. JOYCE, Vice-President, RCA Manufacturing Co., Inc.; COLONEL JOHN REED KILPATRICK, President, Madison Square Garden Corp.; FRANK W. LEAHY, Director of Athletics and Head Football Coach, University of Notre Dame; Larry S. MacPHAIL, President, Brooklyn National League Baseball Club, Inc.; GENE SARAZEN, Lakeview Country Club; W. G. VAN SCHMUS, Managing Director, Radio City Music Hall
ORIGINATING AT NBC TELEVISION STUDIOS, RADIO CITY

THE PARKER FAMILY
Courtesy of The Andrew Jergens Company

MR. PARKER . . . . . Taylor Holmes
MRS. PARKER . . . . . Violet Heming
MR. DENNISON . . . . . William Lynn
MRS. JENNINGS . . . . . Helen Claire
RICHARD PARKER . . . . . Leon Janney

ORIGINATING AT NBC TELEVISION STUDIOS, RADIO CITY

TELEVISION HANDLES THE NEWSREEL
Motion Picture Newsreel Transmitted from NBC Television Studios
to the New Yorker Theatre Via Television
Courtesy Pathé and Twentieth Century-Fox

INTERMISSION

Through the cooperation of
Colonel Kilpatrick and Mike Jacobs, we present
World's Middleweight Championship Bout

BILLY SOOSE vs. KEN OVERLIN

Between the Rounds Commentary
WILLIAM SPARGROVE

Blow by blow Description
JACK FRASER

ORIGINATING AT MADISON SQUARE GARDEN

LUCY MONROE
Singing The Star-Spangled Banner
(Miss Monroe's dress especially designed for Television by Hattie Carnegie)
ORIGINATING AT NBC TELEVISION STUDIOS, RADIO CITY

-The First Television Program as presented at the New Yorker Theatre, May 9. 1941

THEATER TELEVISION

Theater television was attempted away back in 1930 by General Electric Company and Radio Corporation of America. The first appearance of television in the theater was at RKO Proctor Theater in Schenectady on May 22nd, 1940.

The active images of performers were reproduced on a screen approximately six feet square. The system was developed by Dr. E. F. W. Alexanderson of the General Electric Company and RCA.

Audiences at the afternoon and evening shows saw the musical director, John Gamble, lead the orchestra. The musicians were in their customary position in the pit but the director, a mile away, hearing his men over a telephone line, was present only in image. Merrill Trainer, laboratory assistant of Dr. Alexanderson was seen and heard as he explained the method by which the images reached the theater. Other performers were appearing on the theater vaudeville bill. After their appearance on the stage they were seen in the same acts via television.

The performers appeared before the television camera in an improvised studio in the laboratory at the General Electric plant. Light impulses, converted into electrical impulses or radio signals were sent out by a transmitter in the laboratory on a wave length of 140 meters. A microphone close to the performer picked up his speech and song and converted the sound into electrical impulses which were carried by wire to a short-wave transmitter at South Schenectady from which point they went on to the air on a wave-length of 92 meters.

At the theater R. D. Kell, another assistant to Dr. Alexanderson in the role of control operator, received the picture or light impulses, reproduced them on a small monitor and then transferred these impulses to the light valve, at which point the light was broken up to produce an image corresponding to the subject

Charles "Slim" Timblin Riotously Funny at RKO-Proctor's
Mitzi's Revue Is Another Headliner
Rent A Car U-DRIVE-IT RYAN'S GARAGE
STRAND
VILMA BANKY in A Lady to Love
A Supreme Event Of This Century
Will Take Place
In Schenectady Today
When, at Both Matinee And Evening Performances,
RKO Proctor's Theater
By Special Arrangement With The General Electric Company, Will Present the
First Showing
In Any Theater
In the World
Of the New Miracle of Science
TELEVISION
It Is Newer Than Tomorrow's Newspaper!
It Is More Startling Than The First Motion Picture!
It Is More Wonderful Than The First Wireless Message!
It Is More Significant Than The First Telephone!
Naturally, the First Opportunity to Inaugurate This
New Era of Entertainment
Will Most Properly Be Accorded to
The People of Schenectady
Whose Lives Are So Closely Interwoven With the Activities of the General Electric Company
Television, As You Will See and Hear It Today, at RKO Proctor's Is a Tribute to the Combined Genius and Untiring Efforts of Dr. E. F. W. Alexanderson, Consulting Radio Engineer of Both the General Electric Company and the Radio Corporation of America. Dr. Alexanderson's Splendid Staff of Engineers Is Responsible With Him for the Development of Television
BE AMONG THE FIRST TO SEE TELEVISION—TODAY AT RKO PROCTOR'S THEATER
In Addition to Regular Stage and Screen Show
STATE
The golden calf
"HOLD EVERYTHING"
RKO PROCTOR'S
Today and Tomorrow
FIRST TIME
TELE-VISION
GARY COOPER
7 DAYS LEAVE
HAPPY HOUR
RIVOLI
"The Vagabond King"
COLONY
"The Vagabond King"
LINCOLN
"Half Marriage"

at the studio. Head and shoulders only were shown. A second receiver picked up the sound signal and fed it into loudspeakers which converted the electromagnetic waves into sound.

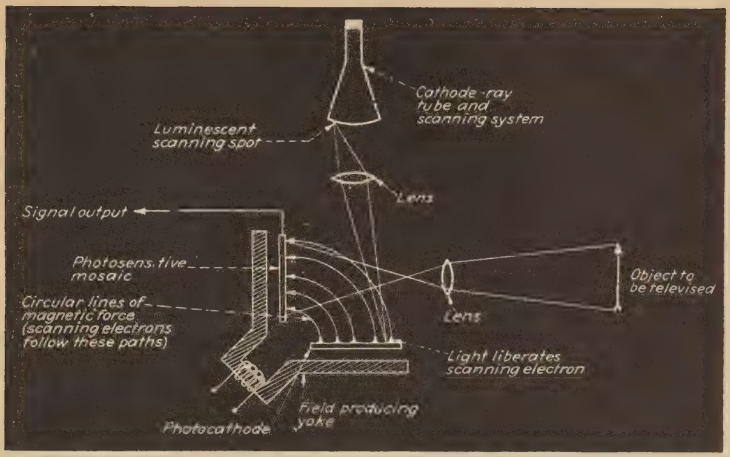
In the studio the subject to be televised stands before an incandescent lamp. Between the subject and the light is a metal disc about the size of a bicycle wheel and drilled with forty-eight holes. The revolving disc covers the subject twenty times a second, that is there are 20 complete pictures made up of light and shade. A large square frame contains four photoelectric cells which respond 40,000 times per second to impulses reflected back from the subject.

The arc-lamp, with the lens system and the light valve, the whole making up the television projector, is placed 17 feet back of the screen. Heavy black cloth from the projector to the screen makes an effective light tunnel which eliminates the possibility of any stray light hitting the screen.

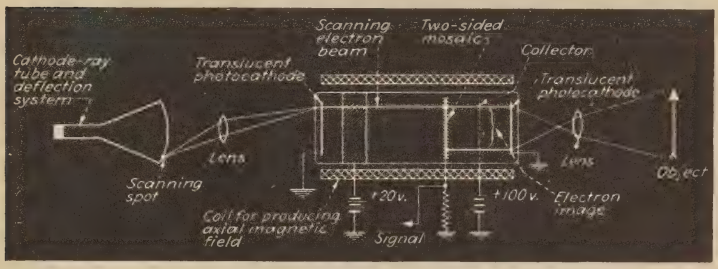
Television has discarded the "scanning disc" in favor of the Iconoscope and the Kinescope, this bringing a new technique.

Basically, the Iconoscope is a vacuum tube in which is mounted a mosaic and an electron gun. The mosiac is a sheet of mica a few inches square, on which has been deposited millions of tiny particles of silver sensitized with caesium. Each particle is insulated from its neighbor by the mica between. On the other side of the mica plate is a metallic coating. The picture is focussed on the front of the mosaic by a suitable lens.

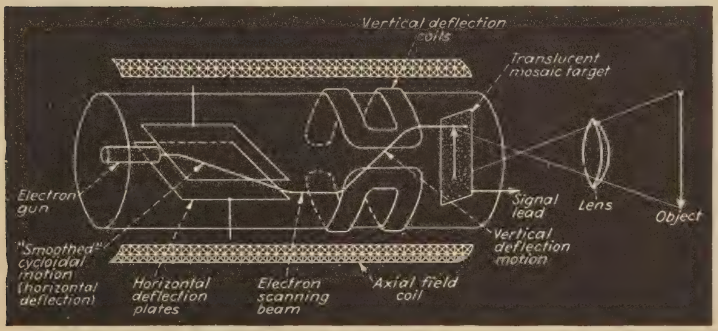
The Kinescope too, is a vacuum tube containing an electron gun producing a sharp beam of electrons (or a cathode ray) and also a grid for controlling the intensity of the beam. On this grid is imposed a voltage proportional to the output current of the Iconoscope. If the spot scanned in the Iconoscope is bright, the grid will permit many electrons to flow, on the other hand, if the spot is dark, the electron beam will dwindle.



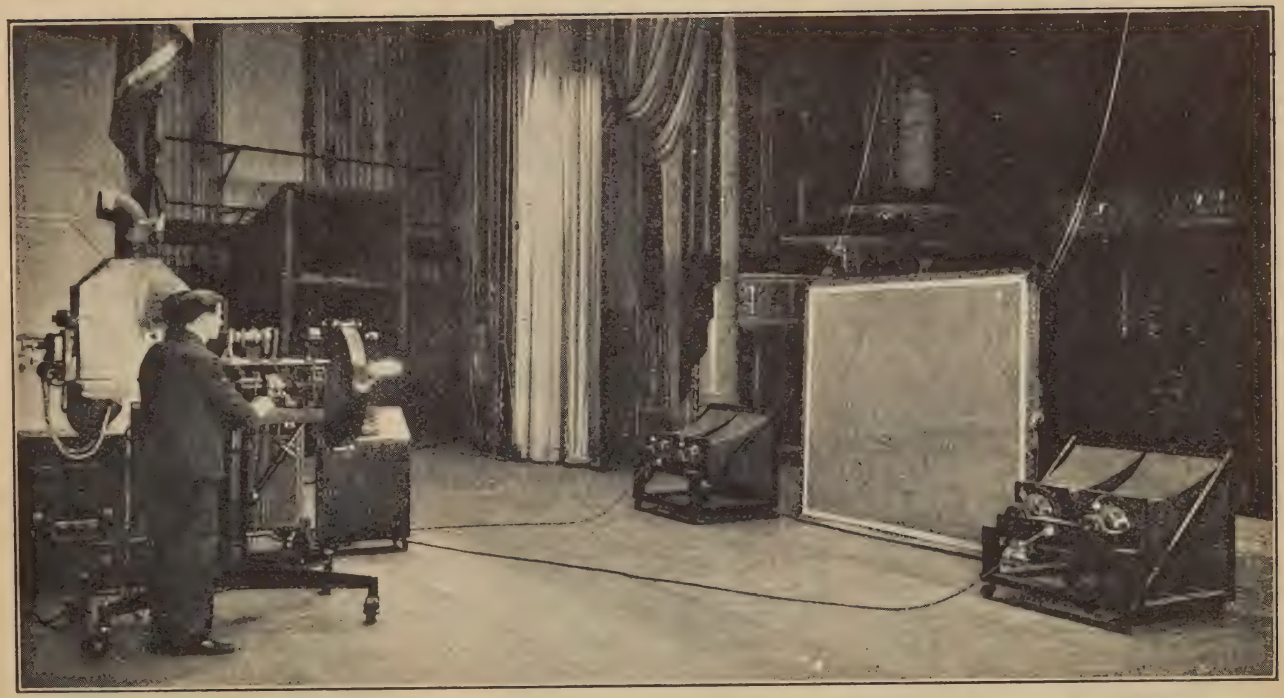
An early system for obtaining perpendicular scanning employed a flying light spot focussed on a photocathode which liberated the scanning electrons



Another developmental form of the tube used a two-sided mosaic, with image on one side and scanning electrons in the other. The flying spot of light was retained



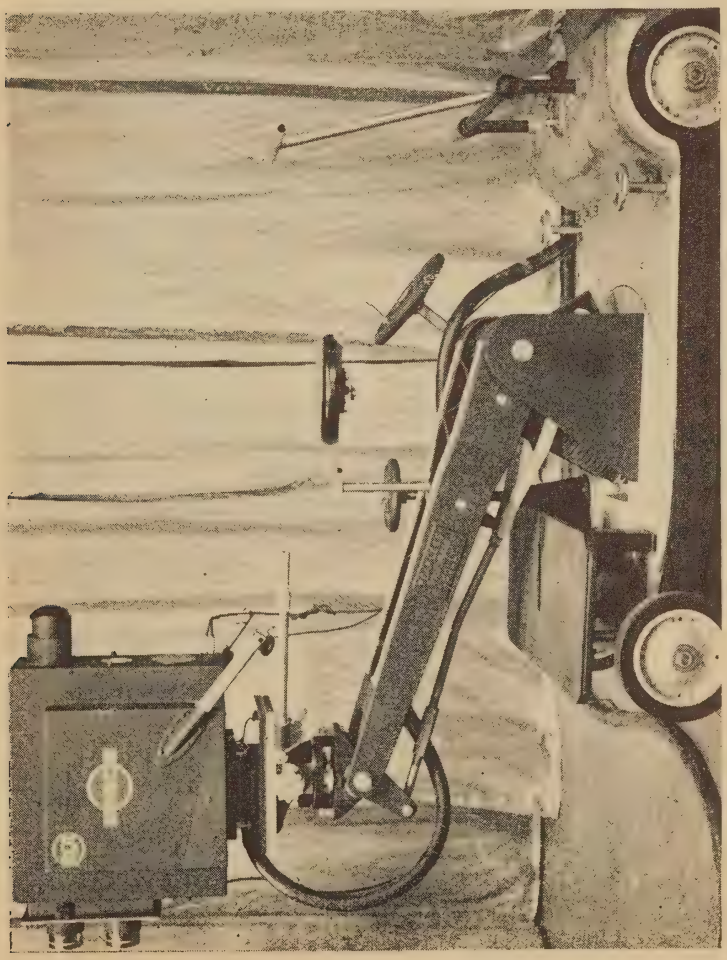
The Orthicon in complete form.



The screen, loudspeakers for sound reproduction and the Karolus projector on the stage of the RKO theater in Schenectady.

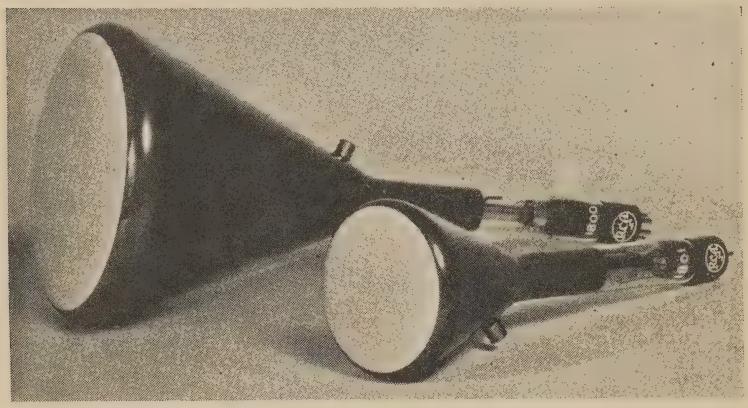
RCA THEATER TELEVISION EQUIPMENT

Large-screen television equipment projected a 15 by 20-foot picture on the screen in the New Yorker theater. There was featured, in addition to new developments in projection, a new multisonic sound system developed by RCA Laboratories for use with the television screen.



Iconoscope camera on camera dolly

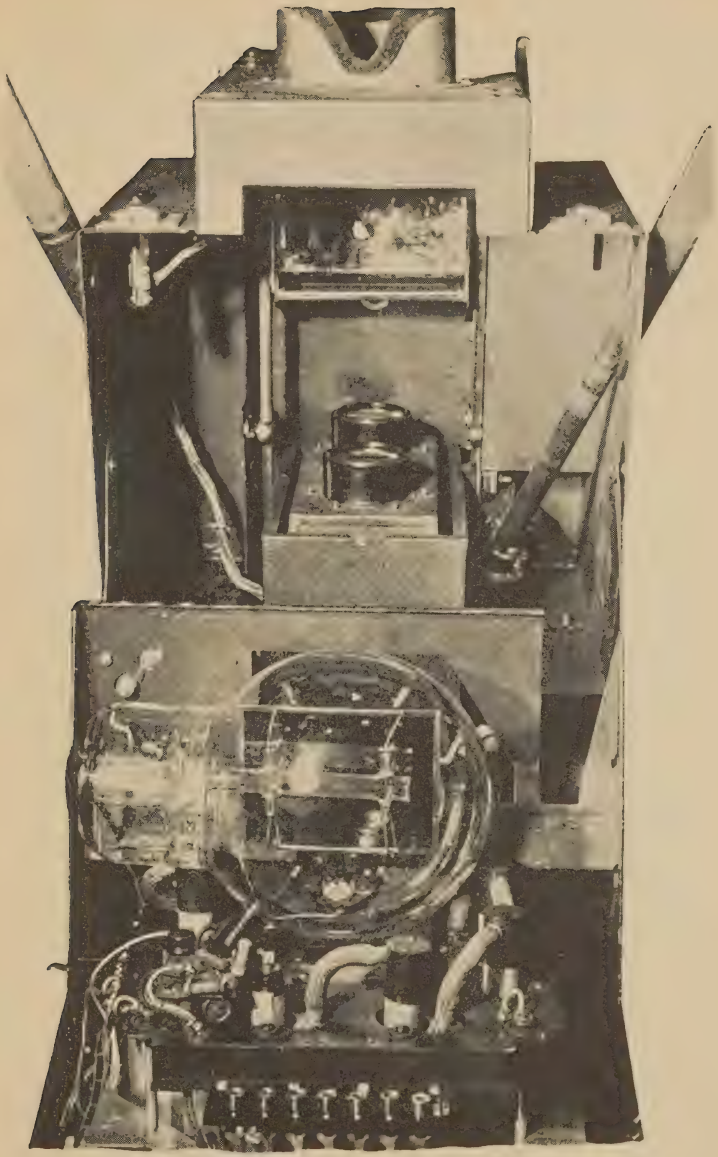
A steel-barreled projector pointed over the edge of the balcony casts the television images on the stage screen 60 feet distant. Alongside the projector are control desks at which operators manipulate the knobs that regulate the picture and sound. These operators exercise the same control over faces and scenes as radio control men do over broadcast music and speech. The pictures, as they come over the wire from an outside point, are received first at the control desk to be fed into the projector. In the demonstration the Camp Upton scenes were relayed by radio to the RCA Building,



–Photograph of Kinescopes RCA-1800 and RCA-1801.

then forwarded from Radio City to the New Yorker Theater over special wire circuits.

The sound reproduction system used in connection with the theater television unit is of the extreme high fidelity type, similar in effect and arrangement to the Fantasound used in the motion picture "Fantasia," and explained elsewhere in this book. Differing from Fantasound in that it is manually controlled at the scene of reproduction, the multisonic system permits movement of sound with action on the screen, rotation of sound around the walls of the auditorium, and ema-



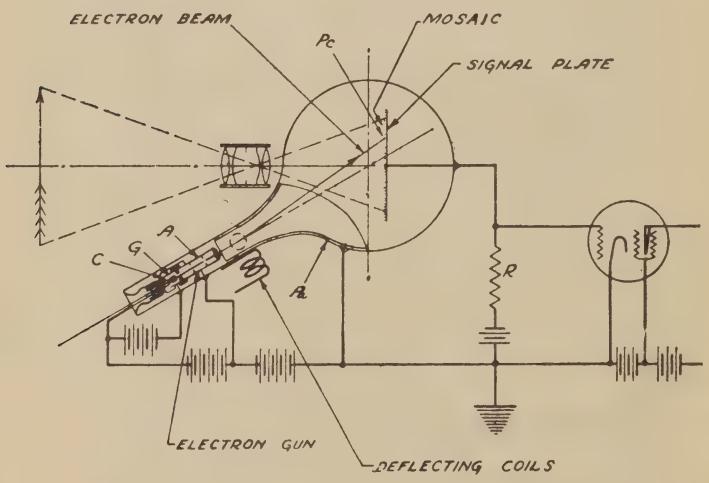
Iconoscope camera, with the housing raised.

nation of sound from any one desired point in the theater.

The large-screen theater television system operates on signals delivered to it either by coaxial cable or by special wire circuits.

The installation in the theater consists of three main units: control, power supply, and optical system.

The control panel gives the operator immediate handling of all controlling, metering, and deflecting elements. He can obtain at any time, every possible check on the operation of the system. Sharpness, bright-

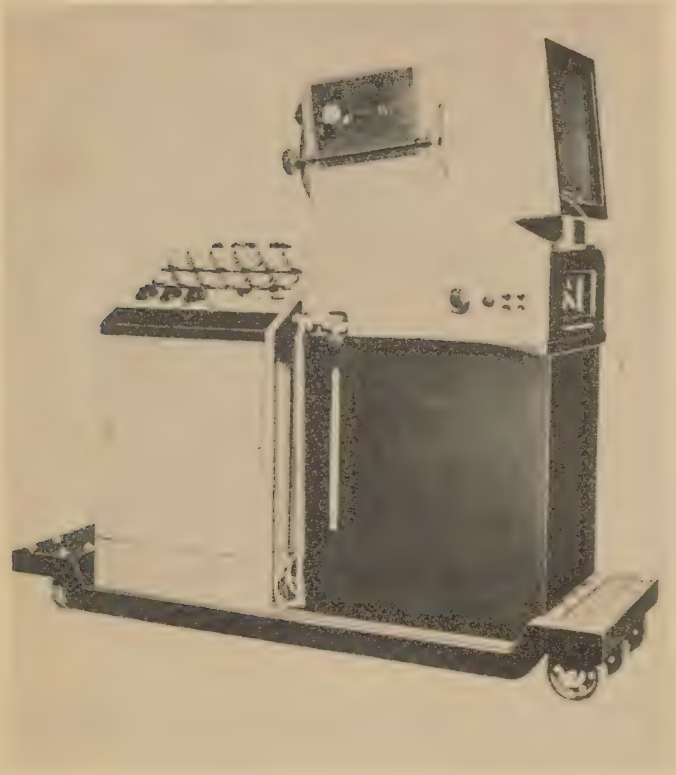


Schematic arrangement of the Iconoscope

ness, contrast, and size of the image projected may be changed by the turn of a knob. The controls are so simplified that the average motion picture projectionist could operate the unit with but slight training.

The second unit, the power supply for the optical or projection system, is a conventional high-voltage, rectifier rated at 70,000 volts. Normally, operation is at 60,000 volts.

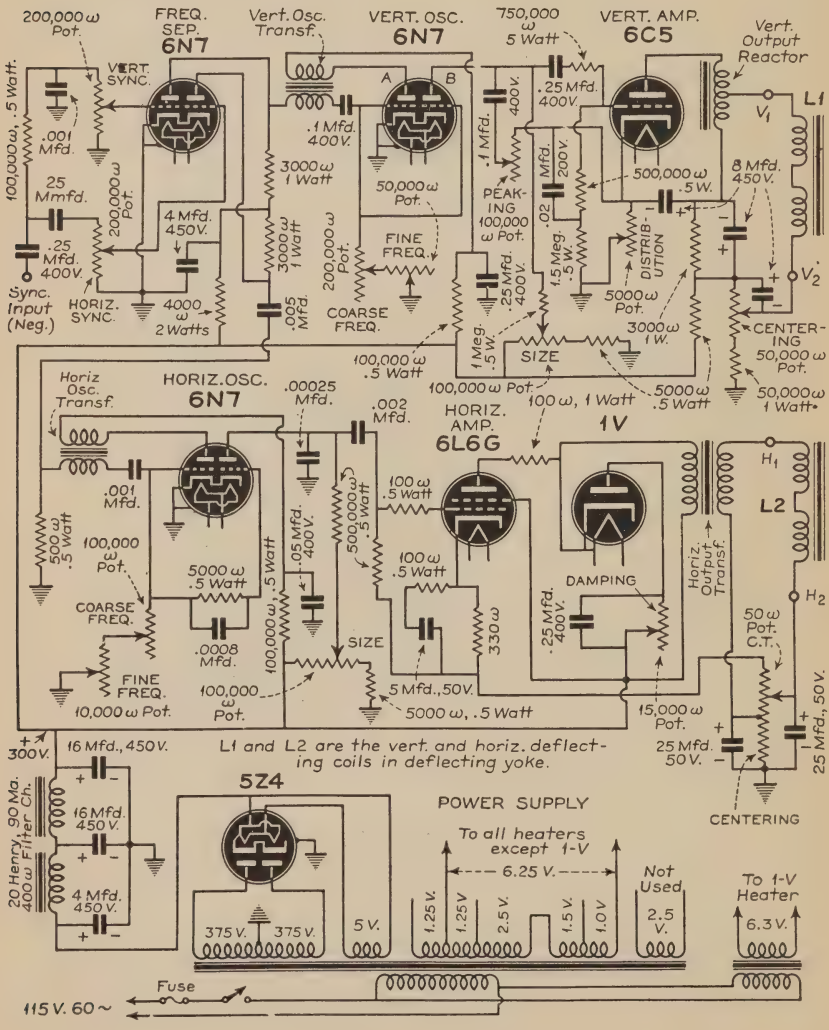
The optical, or projection unit, is considered the most important as well as the most complicated of the entire system. For purposes of description, it is possible to divide the unit into three principal elements: that is, the kinescope, or projection tube; the reflecting mirror, and the correcting lens.



-Early Type Experimental Television Projector

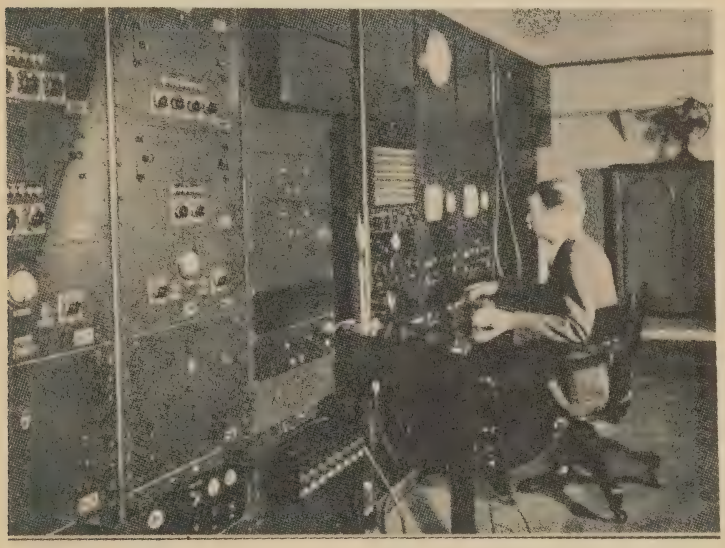
The kinescope, built to handle high voltages, is similar in performance to the kinescope used in RCA's standard home-television receivers. The face or diameter of the tube is 7 inches; the tube's length is 14 inch-

es. It is mounted in the center of a hollow steel-shielded cylinder 34 inches in diameter and 34 inches long. The face of the tube is pointed away from the stage screen,



and the end of its neck pierces a small hole in the center of the correcting plate of the optical system.

The concave reflecting mirror, 30 inches in diameter, is mounted a few inches in front of the tube's face. The image on the face of the tube is picked up on the concave surface of the mirror, passed through the correcting lens and onto the screen with a magnification of 45 times. The lens corrects for aberrations and passes the



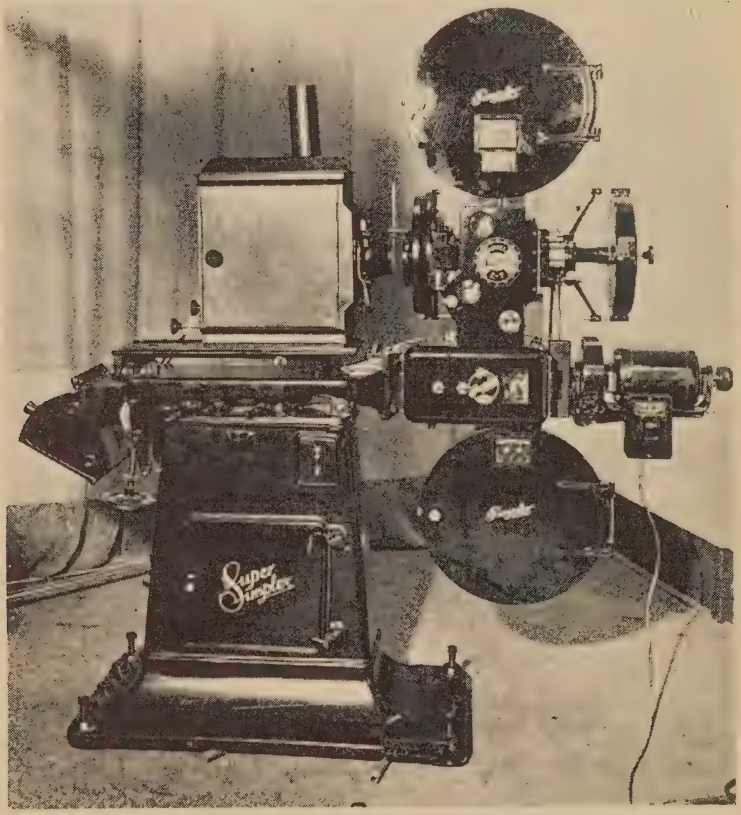
Film studio control room.

image across the auditorium to the stage screen.

The optical system is unique in that it has a speed rating of f: 0.7, which surpasses the fastest known projection lens. It was developed by research engineers in the RCA Laboratories, and is a variation of the Schmidt astronomical camera. Optical experts viewed the idea in the beginning as impractical, but one of the engineers, whose hobby is optics, figured out a formula, devised special grinding instruments, and successfully developed the optical system. The first unit required six

months to produce, but the technique of grinding the lens was improved to the point where the one used today was ground in six weeks.

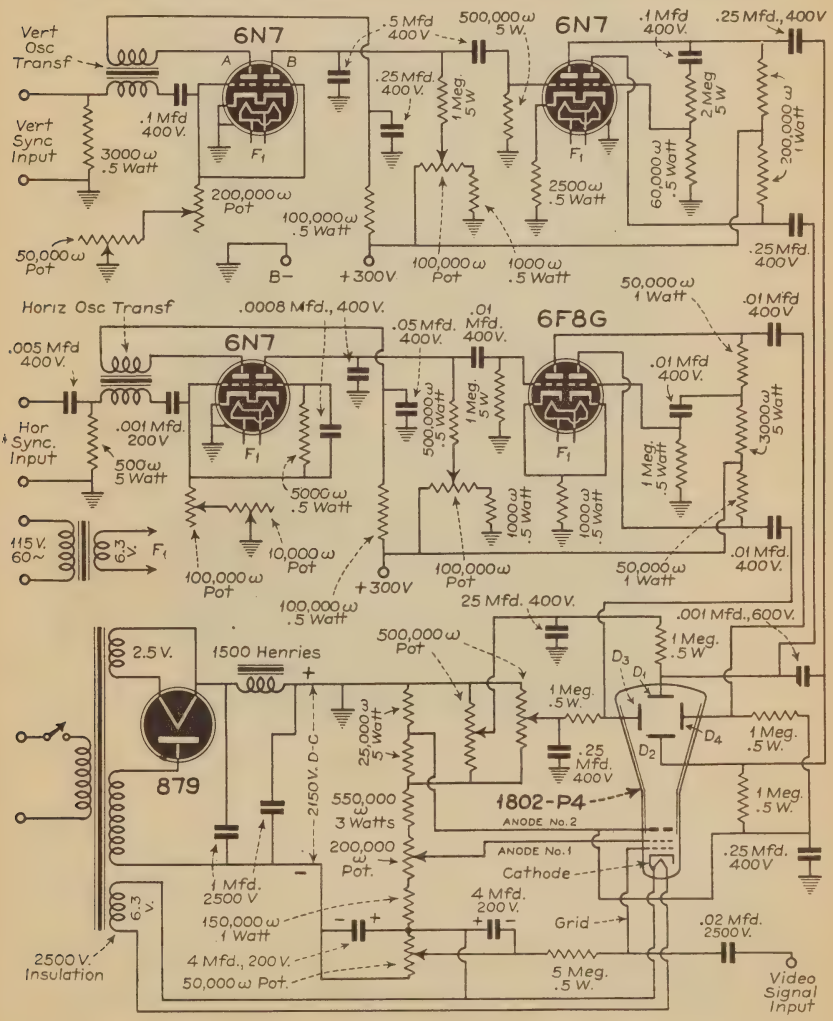
The optical unit housing is mounted on a pedestal which contains the video amplifiers and the deflecting output circuits. Because of the optical unit's high ef-



The General Electric television motion picture film projector.

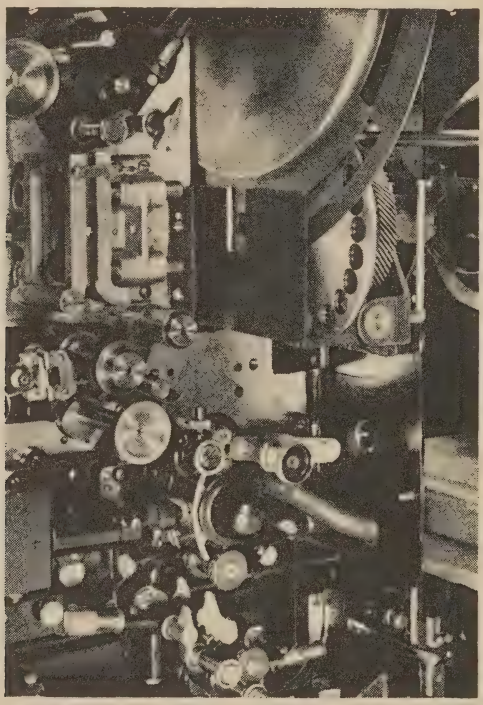
ficiency, the screen illumination obtainable in the system is adequate for large-screen pictures in theaters.

Controls for the sound, which accompanies the television projection, are mounted in a separate console, adjacent to the television control desk. They are linked to 18 high and low-frequency loudspeakers mounted around the auditorium. Wire lines connect the console with the NBC studios and with the central radio re-



ceiving point in Radio City. In addition, there are lines which the sound control engineers use for cueing the program.

Three banks of regular RCA Photophone speakers are set up on the stage near the screen. One bank is at the rear of the screen, and the other two are at either

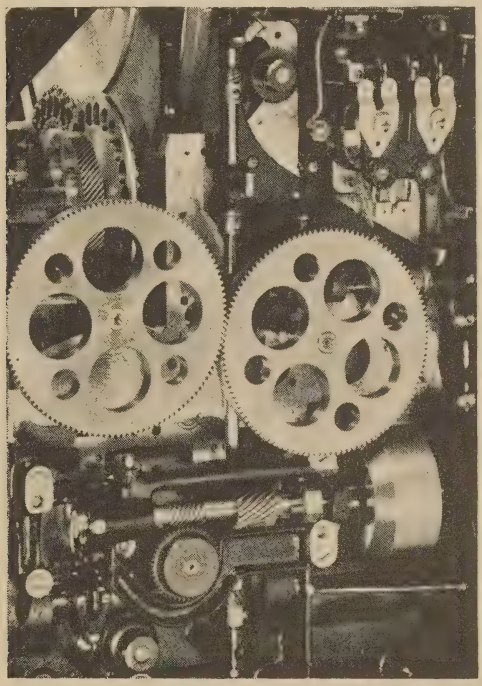


Operating side of projector, showing lens and shutter at interval of projection

side. Beginning at the outer edge of the proscenium arch, other loudspeakers are located at desired points along the side wall and in the rear of the auditorium. One large loudspeaker is suspended from the ceiling.

In installing the sound equipment, engineers incorporated the latest improvements for motion pictures

and radio, as well as recent discoveries in the laboratory. Potentially, the equipment is expected by engineers to create a vivid illusion of realism. At present, however, it is viewed as experimental.

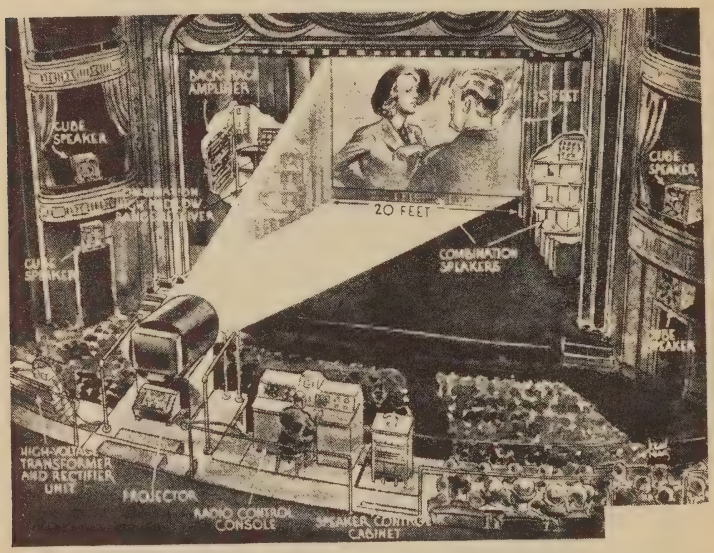


Non-operating side of projector, showing part of special gear train for driving lens discs

The sound control engineer in the theater, taking his cue from engineers at the pick-up scene, is able to cause the sound to move from left to right or right to left, or to remain stationary in synchronization with the action on the screen. Whenever desirable, he can cause the sound to come from the left or right of the house, from the rear, and from above. Also, in effect, he can

make the sound run around the house.

The automatic radio relay of scenes from Camp Upton, Long Island, to New York, brought into use the new unattended radio stations. This radio relay system, developed by RCA Laboratories, incorporates a number of engineering features and innovations in communication. The relay towers, as designed for future use, are envisaged dotting the landscape to make possible intercity television and eventually a television network on a national scale.



Inside the "beacon" on top of the tower is a new horn antenna sharply directional in reception and transmission of ultra-short waves. The towers vary in height, depending upon the terrain and distance to be covered. The automatic apparatus for amplifying and relaying is located in the base of the tower. In a split-second after the pickup and amplification of the signal, the pictures are "search-lighted" in the desired direction.

The mobile units of the National Broadcasting Company, stationed on this occasion at Camp Upton, tele-

vised and flashed the army pictures on the 165 megacycle channel to Hauppauge, 17 miles distant. Haup-

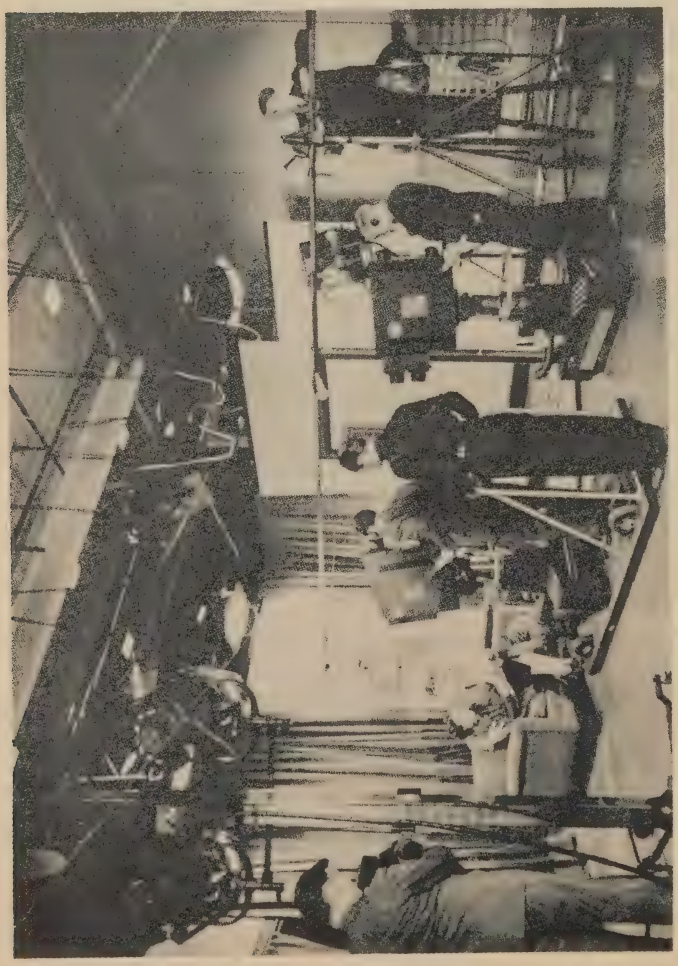
Studio control room.

pauge's automatic relay station intercepted the images and tossed them 23 miles on 474 megacycles to a horn antenna 200 feet up on a mast formerly used by WEAF at Bellmore. There again, amplification strengthened the picture-carrying impulses for relay on 506 megacycles to New York, 28 miles bee-line.

Protruding from a window on the 62nd floor of the RCA Building at Radio City, two horn antennas with their open mouths pointed in the direction of Bellmore, picked up the incoming ultra-short waves that carried the telepictures. These horns, from their 4 by 6-foot openings, taper along the 8-foot length to an apex

about 1½ feet square, where a dipole antenna is located. The impulses were fed into the television sets at Radio City, and also sent over a special wire line to the New Yorker Theater for projection on the 15 by 20-foot screen. The pictures were 441 lines, 30 frames.

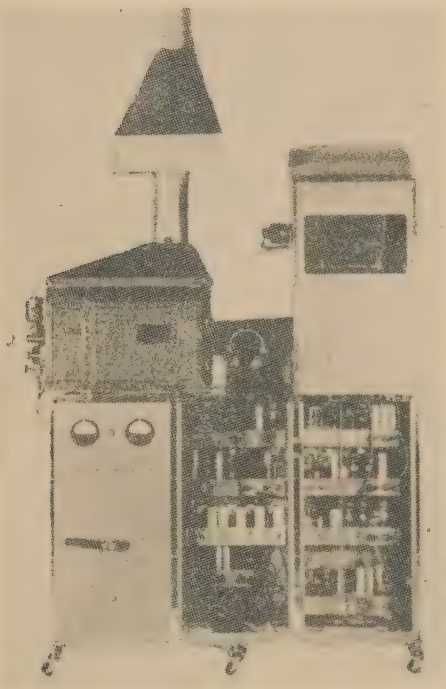
In no instance does the power of the intermediate relay stations exceed 5 watts, an accomplishment attributed in part to the highly directional horn antennas.



One of the earliest lighting arrangements capable of illuminating a single fixed set area.

SCOPHONY TELEVISION

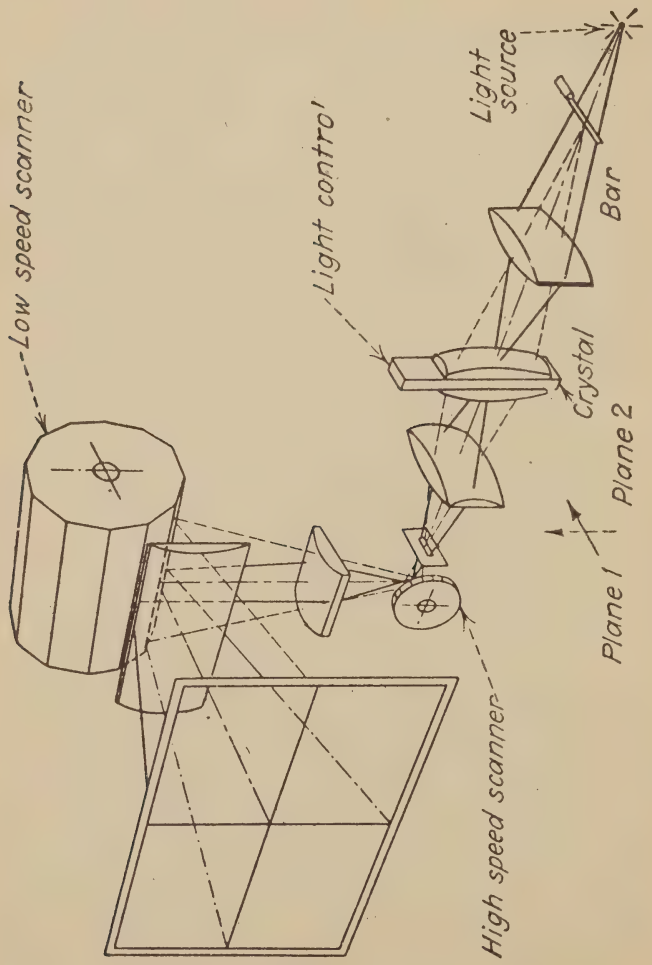
The television receiver projector for theater use is shown in Fig. 349 This is the type of projector now being used at the Odeon Theater and the News Theater in London. On the left can be seen the arc lamp, while on the right some of the mirrors making up the low-speed mirror drum can be seen. All the electrical equipment including the radio receiver, the sound amplifier, the light-control modulator, the drives for the high and low speed polygon, is contained in the two cabinets on the right.



Scophony theater television projector.

Suitable connections are available for the DC supply for the arc lamp, the AC supply mains and for the antenna.

Both vision and sound receivers are built in one chassis. Which as we have already seen, seems to be common practice. The modulated oscillator and synchronizing-signal separation is built on another chassis and

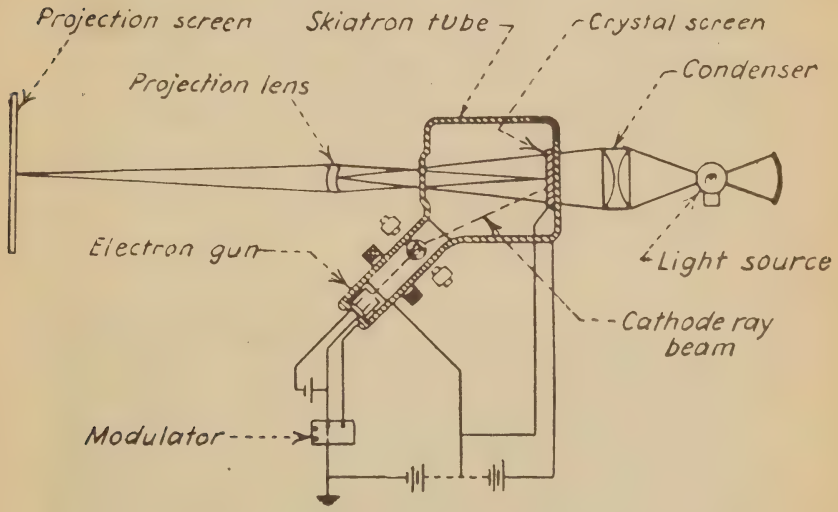


Schematic optical diagram of Scophony receiver for home use, showing arrangement of split focus and light control

is connected to the radio receiver by a plug and socket so that the two chassis are connected together by simply plugging one into the other. This gives a very short video-frequency lead.

The advantage of this system is that both units can be individually tested on the bench and lined up before incorporation in a receiver.

The synchronizing separation is done at high level so that good separation can be obtained even with interference present.



The high speed motor is driven up to its speed, 30375 revolutions per minute in the case of a 405 line picture by means of a synchronous rotor attached to the same shaft as the synchronous rotor.

The synchronous drive unit consists of an oscillator with variable frequency from about 500 to 550 cycles a second, and amplified by means of two tubes, the output of which is split into three phases. The average running up time of a motor including tube heating is about 25 to 35 seconds.

The line-synchronizing pulse is amplified and also fed to two amplifying tubes which are impedance-matched to the phonic-wheel winding of the motor. A small amount of direct current is applied in order to lock the motor rigid.

The low speed scanner consists of an assembled glass polygon driven by means of an ordinary four-pole synchronous motor of standard manufacture running at 1500 revolutions per minute through a single spur reduction gear.

The synchronous pulse is fed directly to a preset multivibrator using a 6N7 tube, amplified by a 6F6 and fed to a pair of tubes in push-pull connection. The output is fed through a matching transformer, and the phase-splitting done by means of condensers.

The phase position of the scanner is adjusted manually on the gear and finally locked. It will be seen that there can be two positions for synchronism, one in frame and the other half a picture out of frame.

MODERN COLOR TELEVISION

Late in 1945 and early in 1946, a series of demonstrations were given of television in color and of television images in three dimensions, also in color. These demonstrations were conducted to show the status and to point out the problems remaining to be solved before color television could be considered ready for development as a public service. The remaining problems are such as to require much additional research and development. However, this chapter is not concerned with these aspects of the situation but rather with a description of the color system and apparatus used during the demonstrations.

Work on broadcast television was interrupted by the war, but advances in electronic and radio techniques during the war period did have a direct influence on television, particularly monochrome television. In order to resume the studies of color television and to evaluate these advances as they applied to television in color, laboratory facilities for research on the various problems involved in the generation, transmission and reception of television images in color together with studio facilities, new circuits and apparatus were developed and placed in operation.

A small studio set was constructed in the laboratory to make possible small scale productions of colorful program material. The set is shown in Fig. 350. Illumination is obtained from an overhead bank of 36 100-watt fluorescent lamps which provide an incident light of about 200 foot-candles. Two auxiliary banks of 24 100-watt lamps each of which can be moved about

as desired in front of the scene to bring the combined illumination up to more than 400 foot-candles. In order to obtain a more uniform light spectrum, half of the lamps are of the white type and half are of the daylight type. By distributing the lamps uniformly on the 3-phase 60-cycle power supply, no difficulty is experienced due to the lights operating on alternating current power.

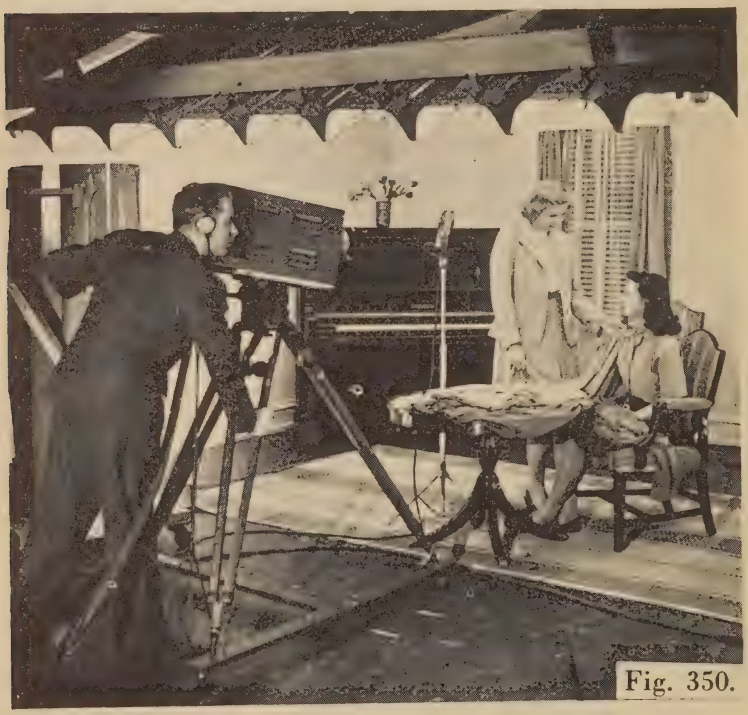


Fig. 350.

CIRCUITS AND APPARATUS

A complete set of experimental equipment was constructed as shown in the block diagram of Fig. 351. The system employs the latest and most suitable devices and circuits which have resulted from many years of extensive research in the field of electronic monochrome television. Added to these electronic compo-

nents are two mechanically rotated tri-color filters so arranged that when the observer is viewing the picture on the Kinescope through a red section of the filter in the receiver, for example, the pickup tube is being exposed to the televised scene through a red section of the filter in the camera. Similarly, when the blue and green filter sections, in turn, are in front of the kinescope, the blue and green sections are correspondingly in front of the pickup tube. The red, blue, and green images are repeated frequently enough so that the

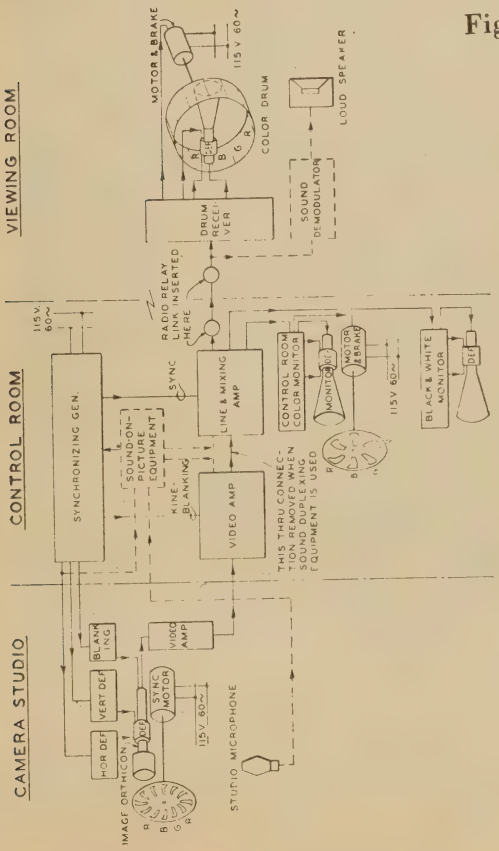
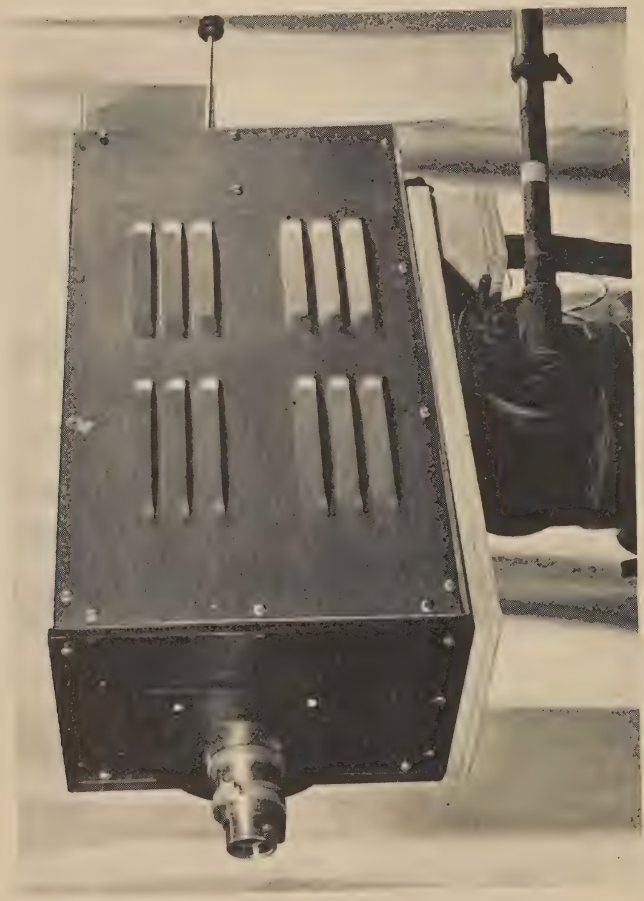


Fig. 351. Block Diagram of Color Television System.

three are superimposed by the "persistence of vision" of the observer, to create the illusion of a single picture in multiple colors.

The operating standards used are: 120 fields per second, 60 frames 2 to 1 interlaced, 525 lines, 40 single-



Experimental Color Camera, Left Side.

color fields or 20 interlaced full color pictures per second. The color sequence is red, blue, green. With these operating standards, the resolution obtained with the

overall system is about 250 lines.

The apparatus is designed so that by slight modification the transmission and reception of color pictures in three dimensions can be demonstrated. For this operating condition, polarizing light filters are incorporated with the rotating color filters at the camera and the kinescope. Special polaroid spectacles are provided for the observers to enable them to separate the right and left images.

During public demonstrations of the color equipment, when it was necessary to transmit the signal to a point several miles away by means of a microwave relay link, it was found convenient to transmit the associated sound on the same radio carrier as the picture by means of a time division duplexing circuit.

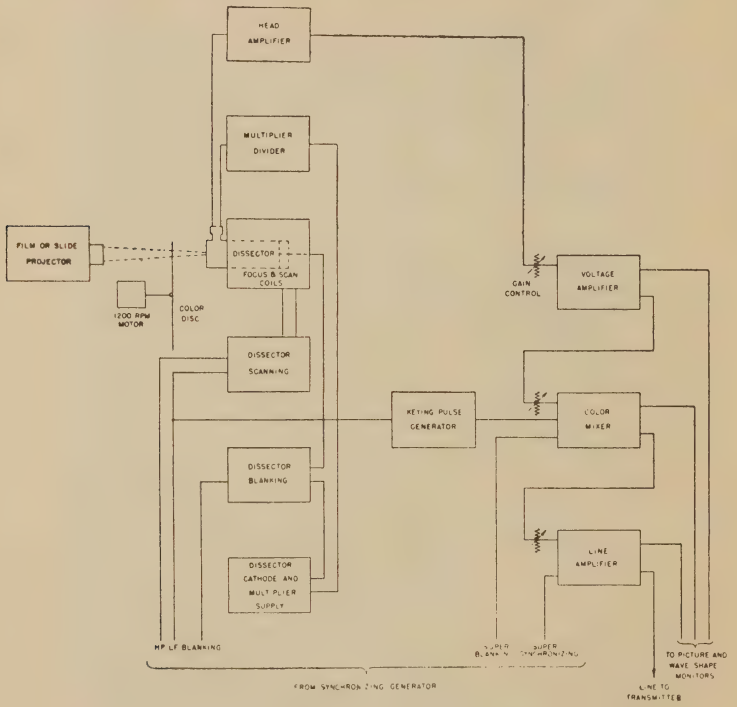
CAMERA

One of the most outstanding new components incorporated in the color system is a special form of the image orthicon. This camera tube is found to have sufficient sensitivity and a sufficiently uniform spectral response to make possible direct pickup of studio and outdoor scenes having an illumination level of from 150 to 300 foot-candles.

Equalization of the sensitivity of the orthicon to the three colors is accomplished by appropriately masking down the aperture on the filter disc for those colors to which the tube is most sensitive, thus reducing the time devoted to storing charges during those particular color fields. Computation of the degree of masking required is based upon measurements of photo-cathode current flowing when the rotating color disc is temporarily replaced by individual color filters. The subject for this test should be a white surface illuminated by the studio lights. After this first color balance has been obtained with a given camera tube, it is possible to operate the camera in much the same way as a conventional photographic camera. For televising scenes under illumination of different color temperatures, the correction is made by the addition of a correcting filter over the lens.

The camera is used with either a 90 millimeter, f:3.5, or a 50 millimeter, f:1.9, Eastman Ektar lens. Both are color corrected. A lens aperture of about f:4.5 is required for the illumination present in the studio.

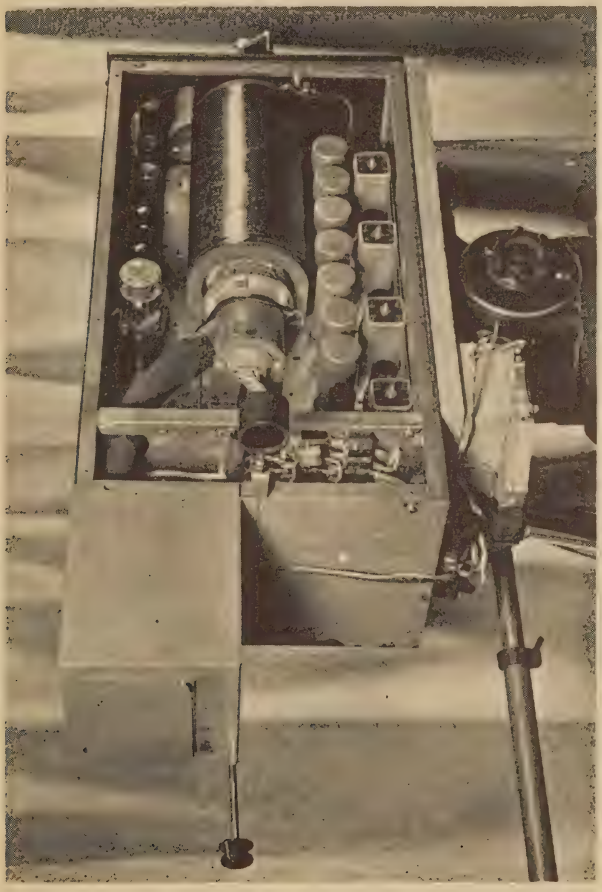
The rotary color disc for the camera is 6⅞ inches in diameter. It has twelve filter sectors clamped with the color balance mask between two plates of glass.



Dissector block diagram.

The filters used are the conventional Wratten tri-color photographic filters, numbers 25 (red), 47 (blue), and 58 (green). The disc is rotated at 600 revolutions per minute by gearing from a small synchronous motor powered directly from the 60-cycle mains. The phase position of the motor with respect to vertical scanning

is adjusted by manually rotating the motor frame. The disc is placed as close as possible to the face of the image orthicon in order to get it near the focal plane of the lens, thus minimizing any optical distortion that may be introduced. Since the image orthicon must operate in a uniform magnetic field of from 60 to 90



Experimental Color Camera, Right Side.

gauss, preferably extending beyond the image section of the tube, the focusing coil is made in two sections, with the smaller forward section being mounted in front

of the color disc.

A multi-conductor cable connects the camera with the control room equipment which is mounted on racks of the conventional type. All electrical controls are on panels in the control room. The video amplifier and the deflection circuits are located inside the camera. All high voltage and plate supply units are located in the control room.

To overcome the difficulties in the camera and terminal equipment due to 60-cycle hum and cross-talk, special power supplies are required. The heaters of the various tubes in the camera are operated from the laboratory direct current power supply. The heaters of the tubes in the control racks are operated on 120-cycle power obtained by using selenium rectifiers across the output of special 60-cycle filament transformers. All plate voltage supplies are regulated and are operated from a 400-cycle source.

The video pre-amplifier used in the camera consists of five stages employing a combination of series and shunt peaking to obtain adequate bandwidth with sufficient gain to raise the signal level to approximately 1 volt peak-to-peak at the sending end of the camera cable.

CONTROL ROOM EQUIPMENT

A view of the control room equipment is shown in Fig. 355. Here is located the synchronizing signal generator, the main video amplifier, the sync-mixing and output line amplifiers, the sound-on-picture terminal equipment, a black-and-white picture monitor, and the direct current power supplies with all camera controls. Control of the video signal amplitude is accomplished by a gain control circuit in the main video amplifier.

Both the synchronizing signal generator and the video amplifiers are standard black-and-white picture equipment modified to operate on color standards. All of the amplifiers used in the system are equalized to beyond 9 megacycles. This would make possible the same degree of horizontal resolution (at twice the scan-

ning rate) ordinarily obtained with black-and-white standards using a 4.5 megacycle channel, provided the other limitations imposed by the color system did not exist.

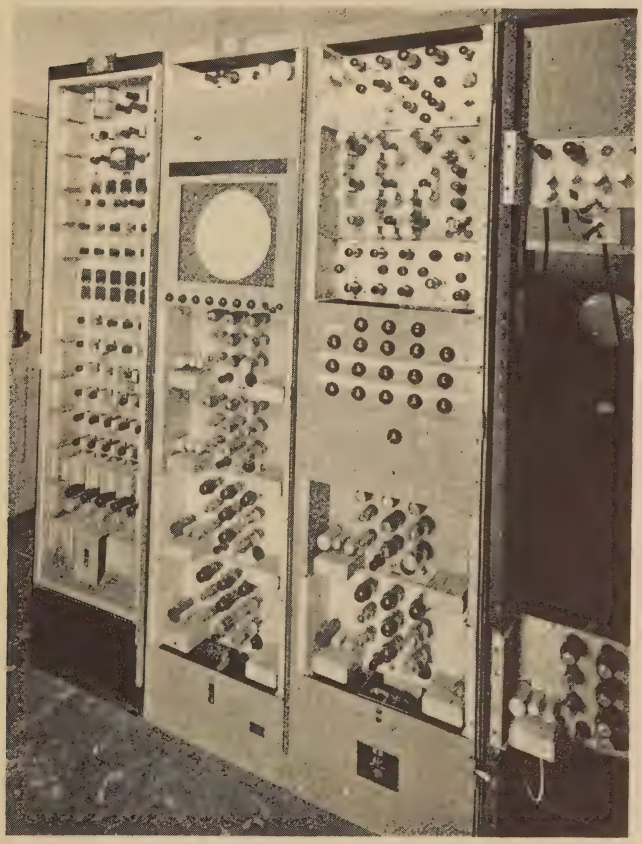
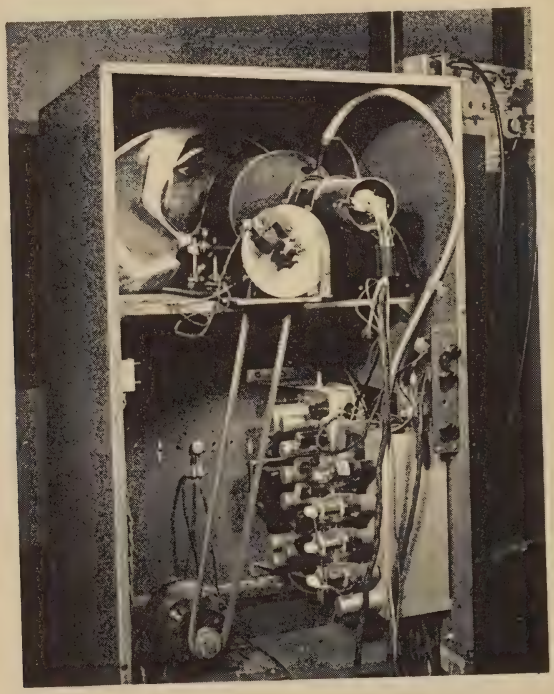


Fig. 355. View of Control Room Racks.

CONTROL ROOM COLOR MONITOR

In addition to a standard 12-inch black-and-white monitor which is useful for checking camera focus, color phasing, scanning, etc., there is provided a color

monitor using 9-inch kinescope having an aluminized screen and operating at a second anode voltage of 15 kilovolts. A 21 3-4" diameter color disc is used in this receiver carrying six filter sections and rotating at a speed of 1200 revolutions per minute. Power to turn the disc is supplied from a 1-8 horsepower 60-cycle induction motor through a belt and pulley drive. This



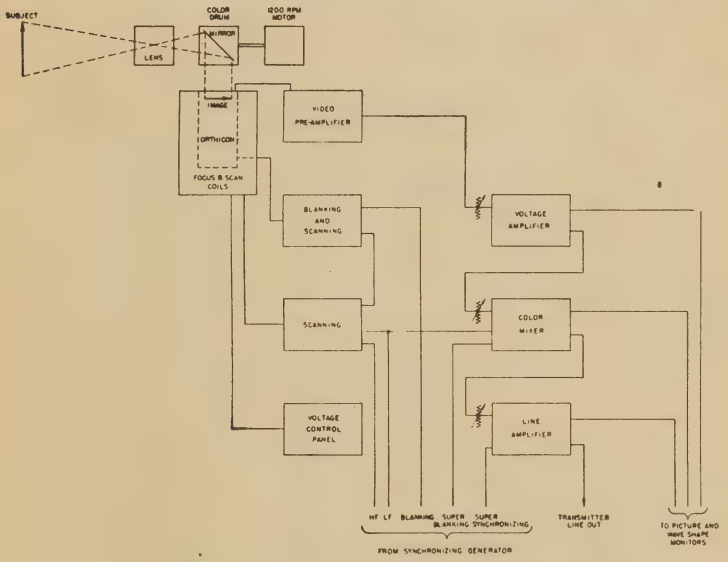
Color Monitor, Rear View.

permits the motor with its disturbing magnetic fields to be located at a considerable distance from the cathode ray tube. Synchronization of the color disc speed with the color field repetition rate is accomplished by a magnetic brake. Proper color frame phasing is obtained by momentarily releasing the brake by manually switching off its controlling current.

DRUM COLOR RECEIVER

For the best viewing by a large number of observers a demonstration receiver was built using a 12-inch persistence, aluminized-screen kinescope operating at a second anode potential of 17 kilovolts.

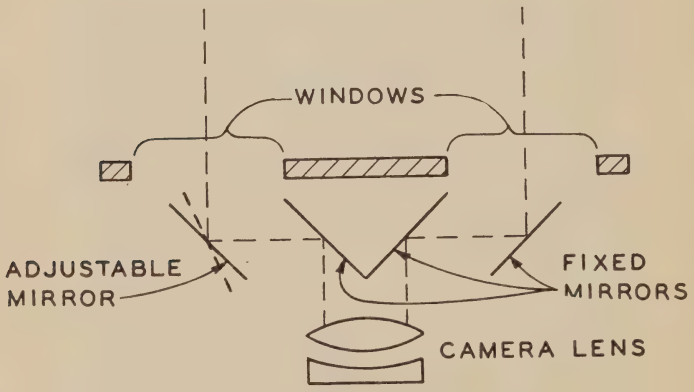
The rotary color filter is in the form of a large drum, one end of which is open to allow the kinescope



Orthicon block diagram.

to be supported inside the drum and at right angles to the axis of the drum by a stationary bracket. The other end of the drum is closed to provide attachment to the drive shaft. The periphery of the drum consists of 12 rectangular red, blue, and green color filter sections clamped in a suitable framework. The drum is rotated at 600 revolutions per minute, in the direction of vertical scanning and in synchronism with the picture field repetition rate. The mechanical drive for the drum is similar to that used for the discs of the control room color monitor.

To overcome the difficulties due to 60-cycle interference in various components of the receiver, several precautions are taken. The kinescope is placed in a large mu-metal shield to protect it from the magnetic fields of the motor and power transformers. The power supply for the tube plates is obtained from a regulated source. All heater power is obtained from a full-wave selenium rectifier.



Light Splitter.

High voltage for the kinescope accelerating electrodes is obtained from a pulse power supply in which the high voltage pulses developed in an auxiliary winding on the horizontal deflection transformer during the "fly back" time are used in a voltage-quadrupling rectifier to obtain 17 kilovolts at a current of several hundred microamperes. With this high anode voltage and the advantage of the aluminized kinescope screen, a screen brightness of 4.5 foot lamberts is obtained in the highlights of the pictures. Since a light loss of approximately 90 per cent is introduced by the color filters, the actual kinescope brightness is 45 foot lamberts. At present a minimum of 10 foot lamberts is considered satisfactory for monochrome television.

TELEVISION PICTURES IN THREE DIMENSIONS

In natural stereoscopic vision the distance to any object (and hence the sense of depth) in the scene is determined by three different properties of the views seen by the eyes. The first is the difference between the two images resulting from the different points of view of the two eyes; the second is the focusing of the individual eyes; and the third is the amount of convergence or toe-in of the two eyes to see a given object in the scene.

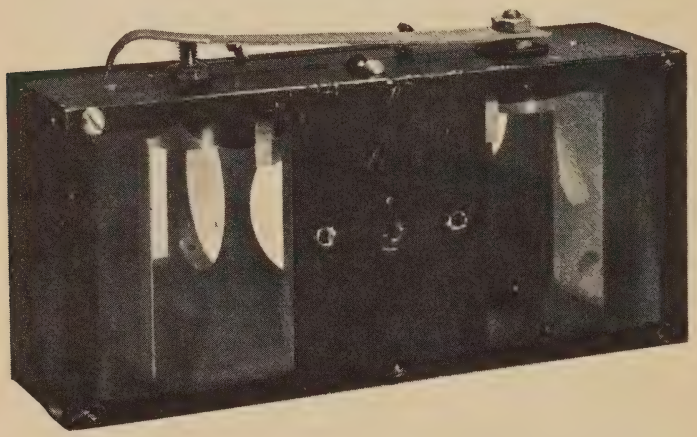
In the stereoscopic television system described here, the images intended for the right and left eyes, respectively, are reproduced on the kinescope screen in time sequence. The two images are separated by polarizing the light from them in planes at right angles to one another by means of sheets of polaroid filter material associated with the color filters on the rotating drum of the receiver as described previously. The observer wears a pair of special polaroid glasses, in which the plane of polarization of each lens is set to agree with the plane of polarization of the picture intended for the corresponding eye.

At the camera, a light splitter is mounted in front of the lens. This attachment consists of a system of mirrors set at 45 degrees behind each of two windows which are spaced horizontally on centers $3\frac{1}{2}$ inches apart. This spacing is a function of the normal interpupillary distance and the overall magnification of the system both optical and electrical.

Sequential separation of the two images is achieved by means of polaroid filters which are placed over each of the windows so that the light coming from the scene as viewed through the left "eye" is horizontally polarized, while that through the right "eye" is vertically polarized. Selection of the particular image to be transmitted during a given field is made possible by means of additional polaroid filters on the rotating color disc with their planes of transmission arranged in quadrature and in alternate fashion. Thus the vertically polarized image is transmitted during one field and the

horizontally polarized image during the next, the unwanted image being suppressed by crossed polarization.

The angular setting of one of the mirrors in the light splitter is adjustable so that the convergence of the camera "eyes" can be set to bring into register some object near the center of the useful depth of field. Observation of this point on the screen of the kinescope corresponds to the situation illustrated in Fig. 326 (A). In this case the object appears to be in the plane of the viewing screen since the angle of toe-in of the eyes is commensurate with the focal distance.



Stereo Attachment for the Camera (Light Splitter).

The image of objects farther away from the camera will not fall at the same place on the screen, but will be separated horizontally a small amount, depending upon their position. Thus the horizontally polarized image intended for the left eye is displaced to the left as indicated in Fig. 326 (B). This condition gives the impression that the object is behind the screen as a result of the angle that the eyes must take in order to obtain fusion of the two images. Conversely, objects nearer to the camera are displaced horizontally in the

opposite direction on the screen as shown in Fig. 326 (C) and thus appear to the observer to be located in front of the screen.

The optical adjustments of the system can be made to give ortho-stereoscopic pictures for one viewing distance and screen size. When more than one receiver is to be operated from a given camera, and if different amounts of magnification are to be used, some correction for the depth and perspective distortion can be obtained by keying the horizontal positioning circuit field by field thus changing the horizontal displacement of a given object on the sereen, and hence its apparent position relative to the observer.

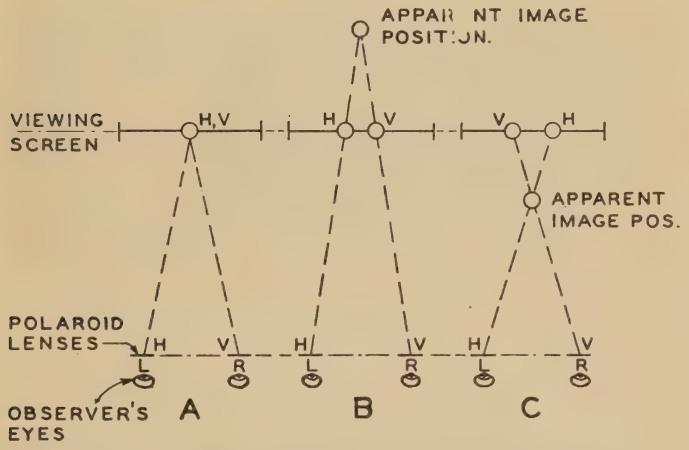


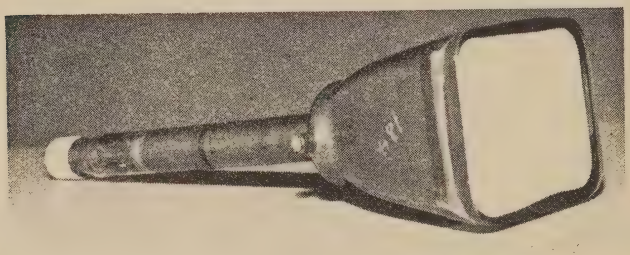
Fig. 326 The Geometry of Stereo Viewing.

SOUND-ON-PICTURE EQUIPMENT

During certain public demonstrations of the color television apparatus the receiving equipment was in another building several miles from the studio. A microwave relay link operating on a frequency of 10,000 megacycles was employed on these occasions for transmission. The associated sound signal was transmitted on the picture carrier by means of a time division du-

plexing system.

The essential elements of the sound-on-picture equipment are shown in dotted lines on the diagram of Fig. 351. The sound modulator is inserted between the video amplifier and the output line and mixing amplifier and keys a rectangular pulse into the "back porch" of the horizontal blanking. This pulse is of constant amplitude extending down to white level and is adjustable in width in accordance with the audio modulation amplitude. In fact, the variable width modulation system is similar in many respects to the variable area sound track as commonly used for sound motion pictures.



Rectangular flat-screen cathode-ray tube for color television.

Demodulation of the duplexed sound channel is accomplished at the receiver by means of a synchronized electronic switch which serves to exclude all but the sound carrier pulses. An amplitude limiter removes amplitude noise. This sound system has the basic theoretical limitation that the maximum audio frequency that can be transmitted is one-half the horizontal line scanning rate, or 15,750 cycles for the color system employed. A further minor reduction in the available bandwidth is due to the cutoff characteristic of the low-pass filter which is required to exclude frequencies above 15.750 cycles.

TELEVISION, TROUBLE-SHOOTING

OPERATING PROCEDURE

Open the lid of the cabinet to the correct viewing angle, about 45 degrees. Then turn the Fidelity-Selector Control, on the radio panel to "TELEVISION" fully clockwise. It is good practice to turn the Brightness and Contrast controls on the television panel fully counter-clockwise to reduce spot illumination when power is applied.

Next turn Power Volume Control on radio panel clockwise and advance about half-way. Allow time for a warm-up period. Set the Station Selector on the television panel to the desired television station.

With the Contrast Control fully counter-clockwise, turn Brightness control slowly from a clockwise position until illumination of the screen almost disappears. Advance the Contrast Control until the picture appears at its best as viewed in the mirror. The contrast control turned too far clockwise will cause blurring.

In the course of these adjustments it may be found that the received picture is out of synchronism. If Horizontal Hold Control is incorrectly set, the resulting picture may appear as shown in Figs. 526 and 527. It should be turned until the picture "locks-in" horizontally. With this adjustment completed, the resulting picture may be unstable in the vertical direction, and may appear as shown in Fig. 528. The Vertical Hold Control should then be turned until the picture "locks-in" vertically.

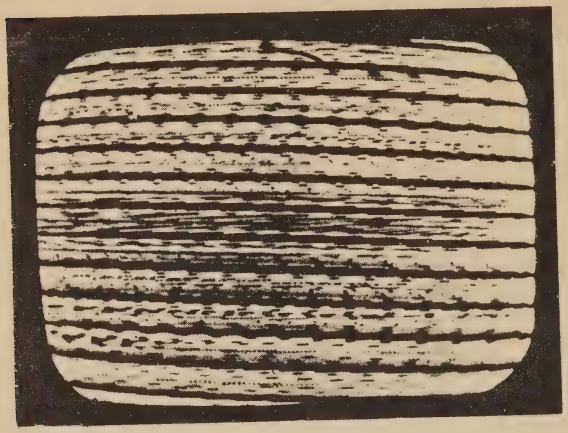
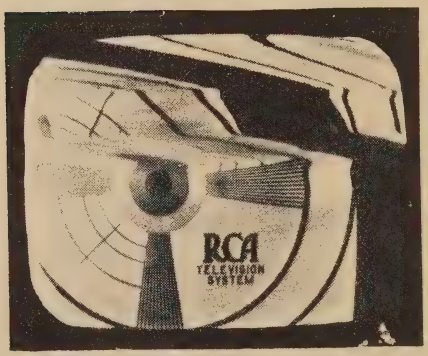


Fig. 526

Fig. 527

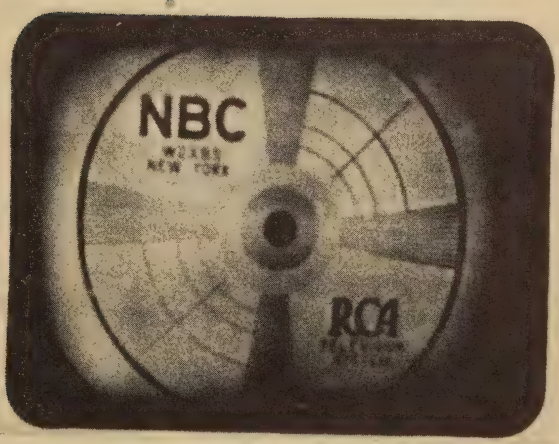


Misalignment resulting from horizontal hold control being incorrectly set.

Fig. 528

Illustrating results obtained when vertical hold control is incorrectly set.

Fig. 529



Focus Control Incorrectly Set

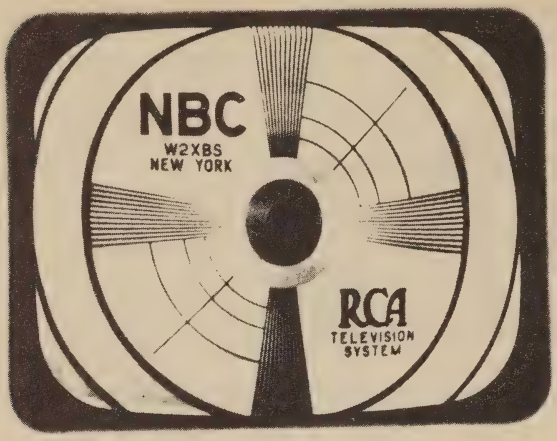


Fig. 530

Contrast Control Advanced Too Far

Fig. 531

With the picture stabilized, the Focus Control should be adjusted to give the best detail observable, or the sharpest picture. Fig. 529 illustrates an out-of-focus picture.

Make final adjustment for the best picture by adjusting both Contrast and Brightness Controls. Figs. 530 and 531 illustrate various conditions of adjustment. Too much contrast gives blurred details, lack of half-tones and too black in the dark sections. While too much brightness makes the picture appear too white or "washed out." Fig. 532 illustrates a poor adjustment of Brightness and Contrast Controls as the vertical lines can be seen.

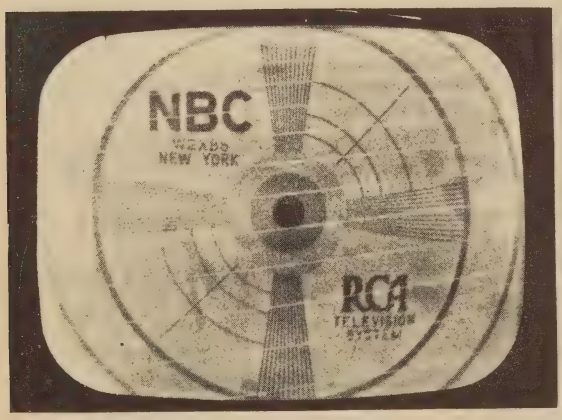


Fig. 532

If a moving ripple (horizontal black and white bars interfering sound in picture) is observed moving across the picture, adjust the Fine Tuning knob for an elimination of the condition. Fig. 533 illustrates a serious condition of sound cross-talk in pictures.

LINE VOLTAGE CHECK

With the receiver controls set for television reception, the line voltage should be checked at the outlet supplying AC power to the receiver. If a duplex outlet supplies the power, the AC voltmeter should be plugged into the vacant receptacle, thus enabling the line voltage to be measured with full receiver load.

If no duplex outlet is used, a multi-tap may be temporarily installed for measuring the line voltage with receiver load. The line voltage, as measured, should be within the limits specified for the particular receiver installed.

Fig. 533

PICTURE ORIENTATION AND SIZE ADJUSTMENT

When the transmitted picture or test pattern is first observed on the viewing screen, it is likely that the picture or pattern will be "out-of-square" with the mask aperture.

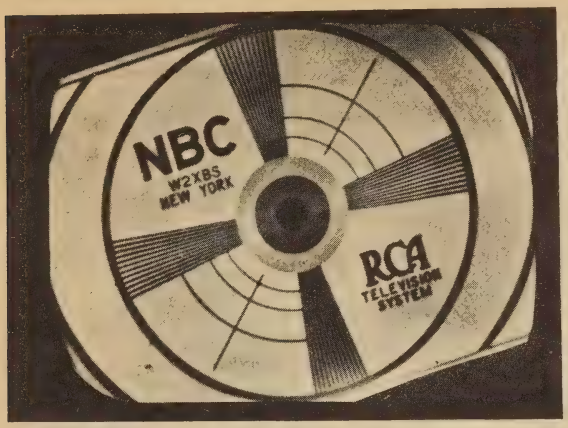


Fig. 534

Fig. 535

Fig. 536

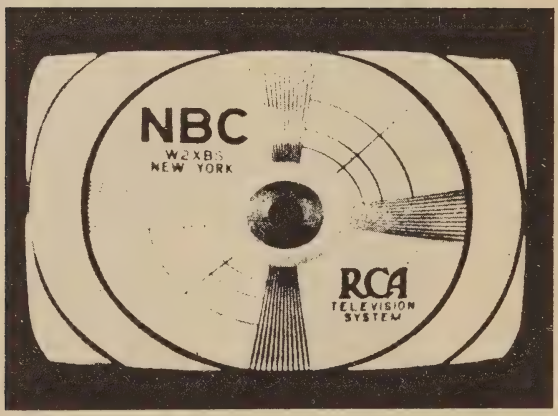


Fig. 537

KINESCOPES, MAGNETIC DEFLECTING YOKES

In the case of receivers equipped with Kinescopes having magnetic deflecting yokes, the latter will need rotation. In order to better observe the orientation, the horizontal width and vertical height should be decreased by adjusting the respective controls until the margins of the picture can be seen. The yoke should then be rotated until the picture margins are essentially parallel with the mask edges. The vertical height and horizontal can then be increased until the mask aperture is just filled by the received picture or pattern.

Fig. 538

KINESCOPES, STATIC DEFLECTION

In the case of receivers having station deflection, the Kinescope itself must be rotated until the picture is orientated correctly with respect to the mask aperture.

The same technique in adjusting width and height, as for magnetic deflecting Kinescopes, should be used.

Obviously, it may be necessary to adjust the vertical and horizontal centering controls during the routine of orientation. Figs. 534, 535, 536, 537 and 537, illustrate improper picture orientation and maladjustment of size and centering controls, which are usually screwdriver adjustments located at the rear of cabinet. Changes in receiver location or ageing of the tubes may necessitate readjustment of these controls.

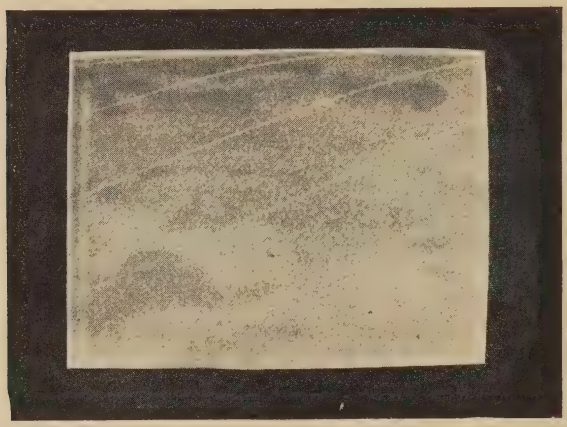


Fig. 539

ORIENTATION WITH RASTER

The foregoing procedure of orientation requires a transmitted signal for observation and is the one recommended for making any adjustments. However, orientation may also be accomplished with reasonable accuracy by observing the scanning pattern or "raster" without a picture signal. In order to prevent noise pulses from causing rough and moving edges on the raster, the picture second detector or a synchronizing amplifier tube may be removed. A correctly oriented raster is

shown in Fig. 539. Note that the vertical return lines, normally blanked out when the picture signal is applied, slope upwards from left to right which indicates that scanning is in the right direction to give a proper related picture.

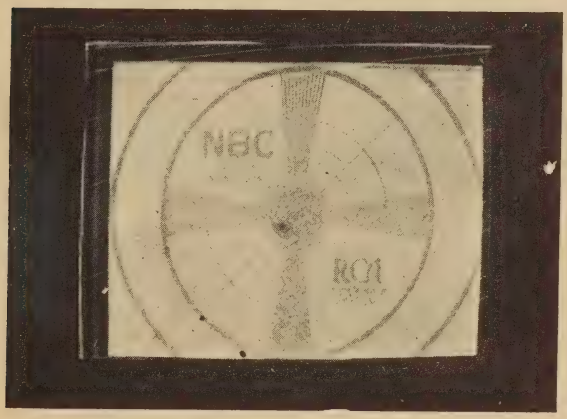


Fig. 540

VERTICAL LINEARITY ADJUSTMENT

When the picture has been adjusted for orientation, size and centering, the picture may appear to be crowded toward the bottom or the top. Such a condition is shown in Fig. 541.

The cause will usually be found to be a maladjustment of the vertical linearity control. An adjustment of the vertical height control, and vice versa.

If the picture fills the mask aperture but is crowded near the top, the vertical linearity control should be turned clockwise, and the height control should be turned counter-clockwise.

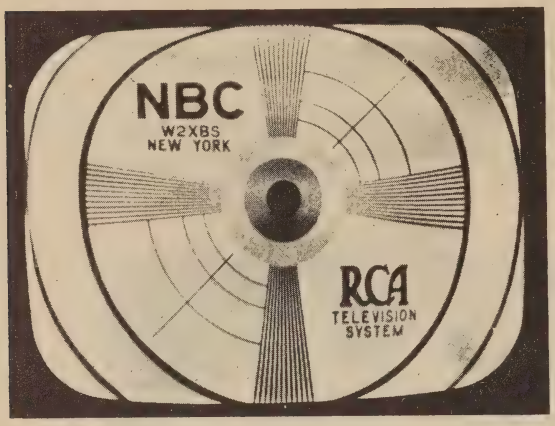
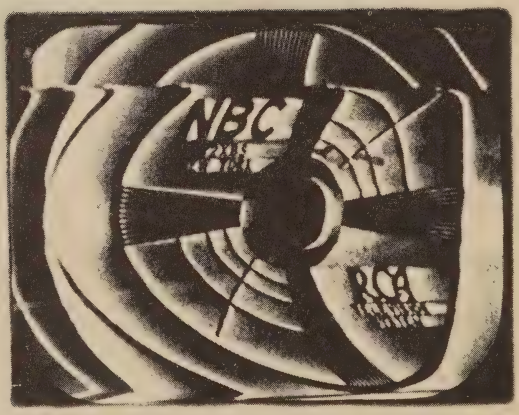


Fig. 541

Fig. 542



Input Signal Too Strong

If crowded towards the bottom, these two controls should be turned in the reverse direction. A slight readjustment of the vertical centering control may also be necessary.

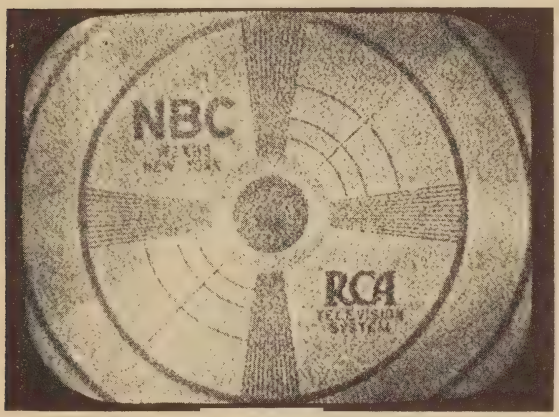


Fig. 543

SERVICE INFORMATION

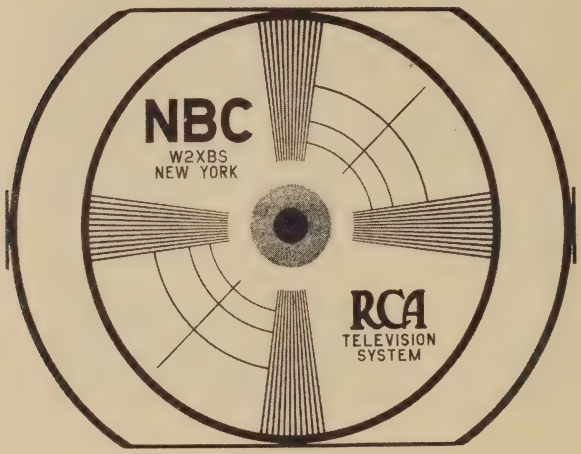
The only positive check of television receiver operation is to use the test pattern signal from the television transmitter. Field strength and interference conditions will be different at every location. Even though the antenna and receiver installations might be tested with a local r-f oscillator, there is no assurance that the antenna and receiver installation will be satisfactory until the received test pattern is actually observed on the receiver Kinescope.

TOO STRONG A SIGNAL

If the voltage at the receiver input terminals exceed

50mv (50,000 microvolts) overload may occur. First indication may be a loss of synchronization and then a picture that appears like that shown in Fig. 542.

Some overload conditions may cause the sound modulation to appear in the picture as shown by the dark and light rippled bands in Fig. 533.



Appearance of Normal Test Pattern

Obviously the remedy is to reduce the signal output. Care must be taken, since too severe reduction in signal strength at the receiver may not allow a sufficient signal-to-noise ratio. The signal input should be measured and then a propeer H pad attenuetor inserted between the receiver input terminals and the transmission lines, so the received signal is below the overload value of 50mv. The H pad attenuator maintains proper impedance match btween line and receiver input while giving the desired signal attenuation.

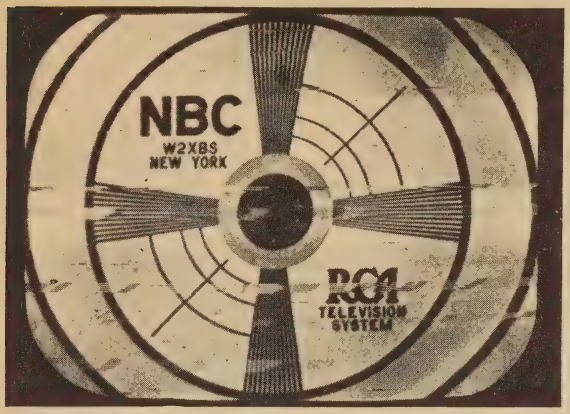


Fig. 544

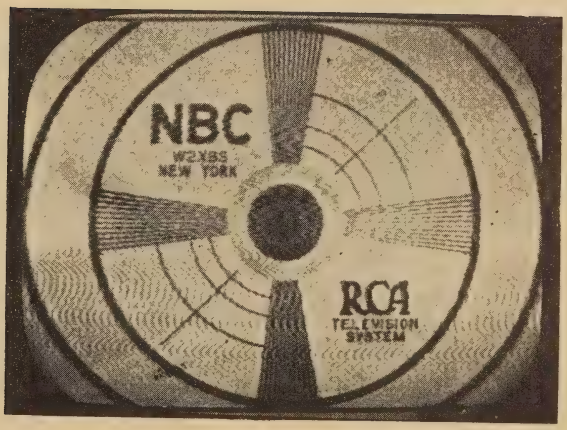


Fig. 545

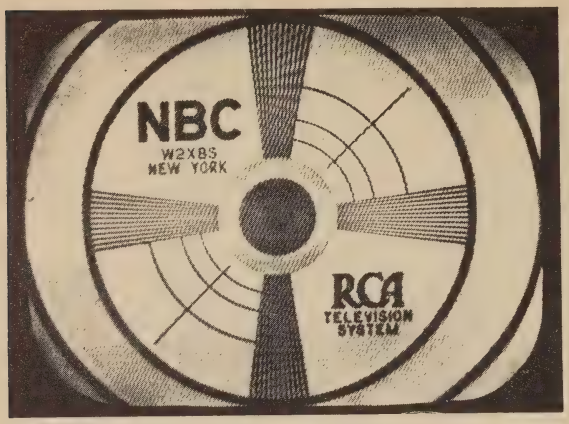


Fig. 546

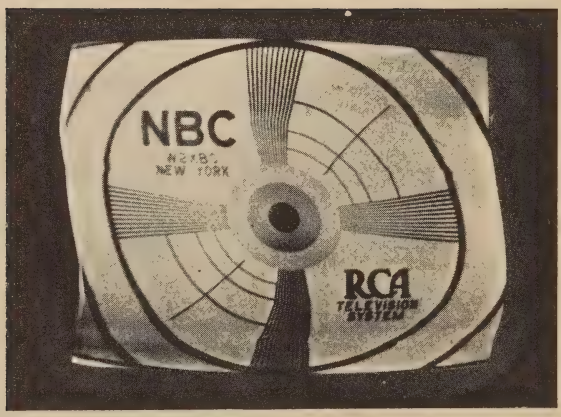
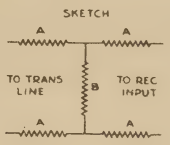


Fig. 547

The table and sketch shown, should be used in making up the required H pad. Carbon rod resistors (1/4

TABLE

APPROX ATTEN	VALUE A IN OHMS	VALUE B IN OHMS
2:1	18	82
4.5:1	27	47
9:1	33	33



watt size) should only be used and their values checked before assembly.

If proper measuring equipment is not available, it is suggested that the various H pads be tried and the one with least attenuation that removes the overload condition be used.

TOO WEAK A SIGNAL

In outlying locations (near the limits of the transmitter service area) and in any location shielded by a hill or congested building construction, the signal reaching the receiver input terminals may be too weak. With this condition the receiver's sensitivity is, of course, "wide open" and receiver hiss (snow in the picture) and external noise interference may appear in the picture making it unsatisfactory. Fig. 543 illustrates receiver hiss which might result from too weak a signal input. The signal may be too weak even to insure stable synchronism as noise pulses may be strong enough to override the signal and so trip the deflection oscillators at the wrong time.

The remedy is to install the antenna at a greater height or in an unshielded location, provided increased transmission line loss does not offset the increase in signal strength due to the higher or clearer locations.

It may be necessary to install a special low loss transmission line or special antenna.

There may be no alternative except the installation of a special r-f amplifier to offset the increased transmission line loss if the location of the antenna causes such loss.

INTERFERING SIGNALS, REFLECTIONS

In very strong signal areas, the transmission line particularly if long and in a horizontal plane, may pick up sufficient signal so that regardless of antenna type and location, reflections may not be removed by positioning the antenna.

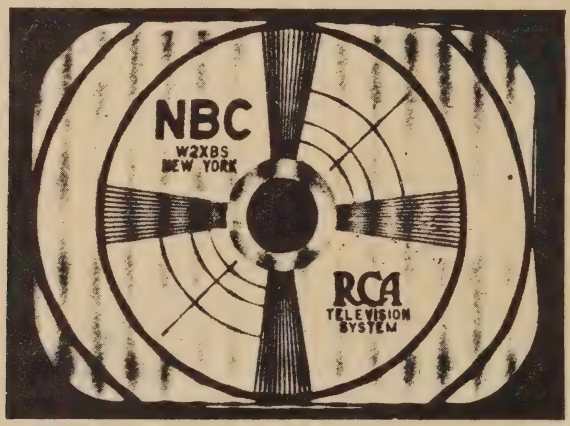


Fig. 549

Special shielded transmission line, such as lead covered cable of the correct surge impedance of approximately 100 ohms and appropriate loss may have to be used.

INTERFERING SIGNALS, AUTO IGNITION

The interference caused by ignition systems ap-

pears somewhat as shown in Fig. 544. Obviously, there is no remedy if the antenna has been installed as far as possible from known sources, such as heavily traveled streets.

Auto ignition may be strong enough to override the received signal in outlying locations, to cause not only the speckles as shown in Fig. 544 (or white spots) but streaks of noise with accompanying loss of instability of synchronization.

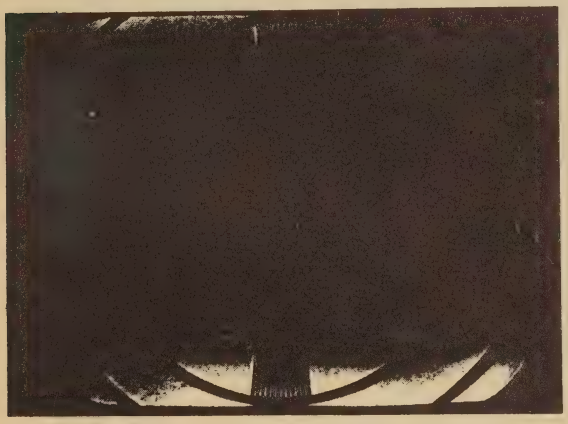


Fig. 550

INTERFERING SIGNALS, DIATHERMY

The interference caused by this type of therapy equipment, usually found in hospitals and doctors offices, appears as shown in Fig. 545.

Here again there is no remedy if the antenna installation is as efficient as possible. However, if the offending machine can be located, the owner may cooperate by seeking to reduce the interference.

Some diathermy apparatus operate on a fixed frequency in the u-h-f spectrum while others the frequency shifts with body electrode lengths and positions. In some cases the interference pattern may drift up and down the viewing screen. In most modern diathermy equipment radiation into the power supply system is reduced by appropriate r-f filters.

Fig. 551

INTERFERING SIGNALS, CARRIER BEATS

If another service carrier should drift so a heterodyne beat occurs between sound or picture carriers the resulting beat frequently may be seen as a series of fine vertical or slanting lines that drift across the screen. In fact the receiver may be mistuned by an adjustment of the fine tuning control to see the beat of 1.5 mc between the unwanted sound and wanted picture carriers of adjacent channels. Fig. 546 illustrates the apparent cross-hatching caused by a carrier beat.

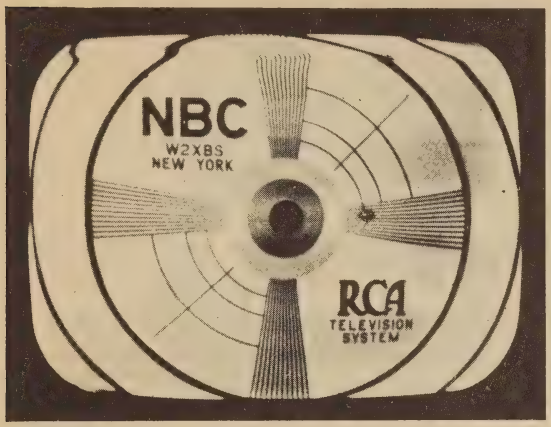


Fig. 552

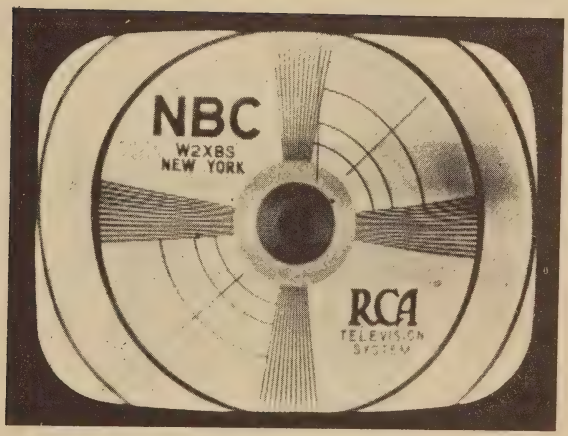


Fig. 553

Fig. 554

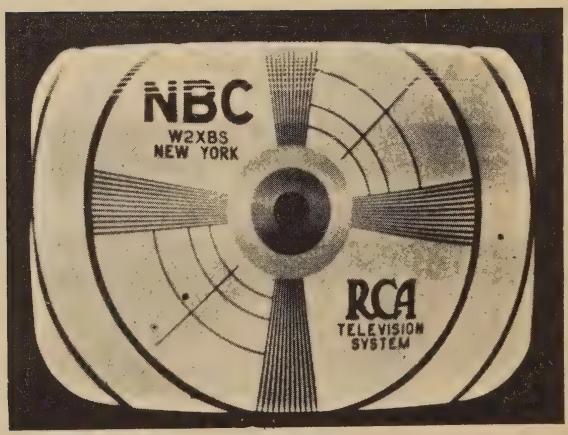


Fig. 555

HUM OR RIPPLE PATTERN

If the receiver is located so its power supply is non-synchronous with the transmitter supply, residual hum in the receiver deflecting circuits may cause a slight weaving of the picture. This motion is most readily seen by reducing the horizontal width and observing the moving or drifting ripple or wavy effect on the edges of the picture.

A very exaggerated condition of 60c hum or ripple in the horizontal deflection circuits is shown in Fig. 547. The effect of 120c ripple would appear as a doubling of the wavy edges shown for the 60c ripple.

The residual hum in the receivers is always kept as low as the economics of design permit. Past experiences has indicated that at normal viewing distances the slight weaving of the picture, when the receiver is operated on a central station non-synchronous supply, is hardly noticeable.

When costs of AC wiring become prohibitively high, the receiver may be operated by a motor-generator, or a rotary converter. The frequency of the rotating machine should be adjusted by accurately controlling its rotary speed. A conventional reed type frequency meter may be used to check the frequency at 60 cycles.

The market affords converter type machines having governor control of the speed which when once adjusted may give satisfactory results in so far as a moving ripple pattern is concerned.

The second class of difficulties to be outlined are those that may be due to receiver faults. Obviously, it would not be possible to list and describe all the possible faults that may occur. Since the sound portions of a television receiver are similar to any high quality sound broadcast receiver, service suggestions on the audio system will be omitted.

TROUBLES DUE TO RECEIVER FAULTS

It is recommended that any failure of normal op-

eration may be traced by first replacing tubes that have a bearing on the effect observed.

For instance, a microphonic first detector or picture i-f tube might cause a sound in picture condition or unstable synchronization. If such replacement fails to remedy the fault, then checks of circuit continuity and voltages at tube sockets should be made.

Fig. 556

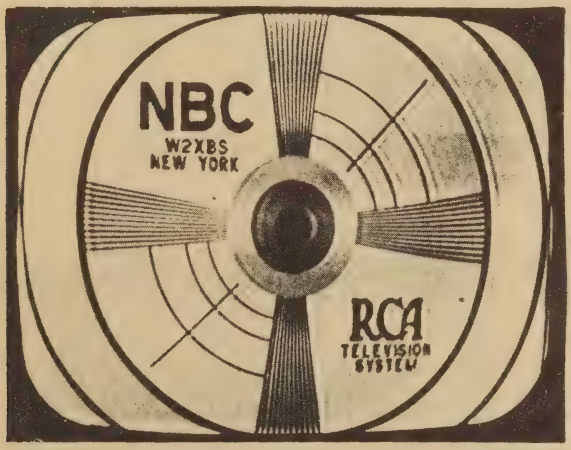
It is well to remember that all television receivers have high voltage supplies that may cause a lethal shock. Do NOT make any high voltage circuit checks, other than continuity. Carefully read all service notes before making any voltage measurements.

Socket adapters should never be used, as lead changes may cause oscillation and erroneous voltage readings. Loose or poorly soldered connections may be more easily found by lightly tapping the chassis and parts with a rubber headed mallet. A defective joint will usually be evidenced by noise in the loud speaker.

Critical circuit components such as the oscillator inductances however should never be displaced in any service work.

If any parts are replaced in the i-f, video or horizontal or vertical synchronizing and deflection circuits, the lead lengths, part placement and lead dress should be maintained as originally found.

All alignment adjustments are sealed at the factory with special cement or springlocked in place. There is little likelihood that they will need readjustment and they should therefore never be tampered with. No alignment of any nature should be attempted without proper cathode ray oscillator and oscillator sweep circuits.



Distortion of Pattern Due to Peaked High Frequency Response

TROUBLE AND CAUSES.
NO KINESCOPE ILLUMINATION

The high voltage (up to 7,500 volts) used for second anode supply may cause a lethal shock. All work

on the high voltage circuits should be performed with the power turned off, this may be done by removing the power supply cord from the power supply outlet.

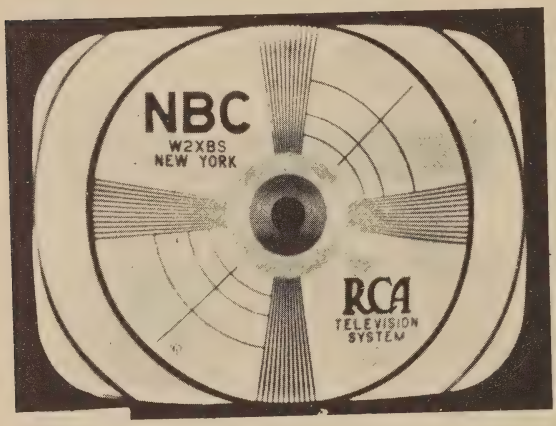


Fig. 557

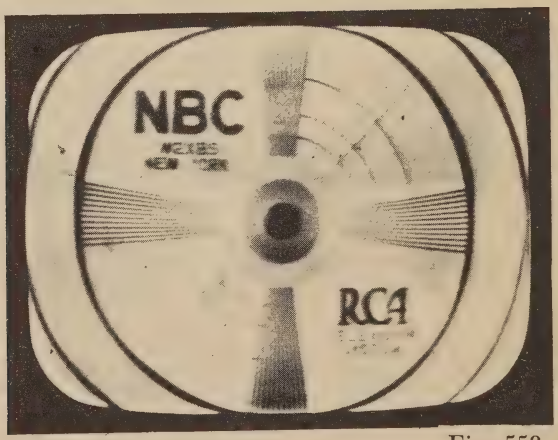


Fig. 558

Always discharge the high voltage condensers by connecting to ground while working on the receiver. Use a high voltage insulated lead and always connect to the ground first. It is good practice to use only one of your hands, keeping the other hand in your pocket. Do not tamper with or eliminate the protection provided by the safety interlock switches.

Continuity checks of the high voltage circuits should be sufficient to locate any suspected trouble.

No Kinescope illumination may be due to any one of the following—

(1) Defective Kinescope.
(2) Defective high voltage rectifier tube.
(3) High voltage bleeder.
(4) Defective power transformer.
(5) Shorted high voltage condenser.
(6) Defective brightness control.
(7) DC restorer circuit placing too high a bias on control grid.
(8) Second anode lead disconnected.
(9) Defective wiring.

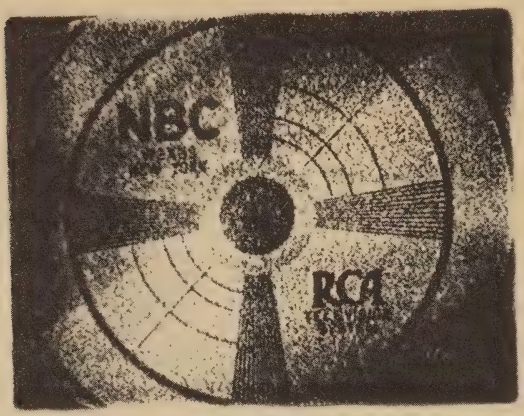
A shorted or gassy high voltage rectifier tube may cause the filter resistor between the high voltage condensers to burn up, causing no illumination.

NO DEFLECTION OR SCANNING

If only the electron scanning spot is seen, turn the receiver off, as the stationary spot may damage viewing screen. Investigate continuity of deflection circuits as yoke leads or plug may be disconnected or open. Replace the deflection circuit tubes. Check supply voltages.

If only a vertical line is seen, turn the receiver off as the stationary line may damage the viewing screen. Observing only a single line indicates immediately that there is no horizontal deflection which isolates the trouble to the horizontal deflection circuits.

Similarly if only a horizontal line is seen, the trouble lies in the vertical deflection circuits. In any of



Input Signal Too Weak

Improper Interlacing

these observed faults the prompt manipulation of the centering controls will determine if the deflecting yoke is in operation.

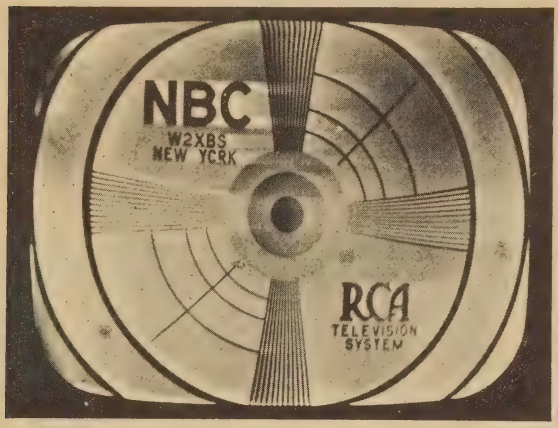


Fig. 559

NO PICTURE

If the transmitter is known to be on the air and no picture is seen, the trouble may be anywhere between the antenna and Kinescope grid. Assuming that the antenna and transmission lines are OK, the fault may be traced to any of the following—

(1) Defective tube in r-f oscillator, first detector, picture i-f, second detector or video amplifier.

(2) Open grid cable to Kinescope or defective Kinescope.

(3) Defective contrast control.

(4) Defective part or connection.

The loss of the picture signal may be quickly isolated by a step to step procedure, as follows—

Distortion which results when horizontal centering control is incorrectly set.

When the horizontal width, or size, control is incorrectly set, this is the result.

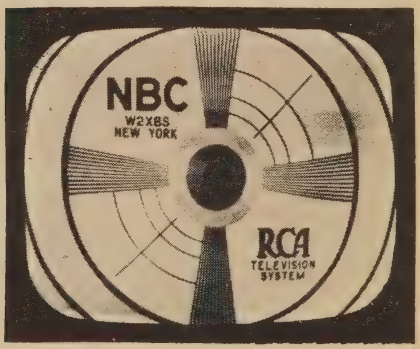
(1) Apply through a 0.25 mfd condenser some AC voltage from any heater to the control grid of the video amplifier tube. An AC hum pattern similar to that shown in Figs. 550 and 551 should be seen if the video amplifier to Kinescope grid is in normal operating condition. The RCA stock No. 153 Test Oscillator may be used, using an unmodulated frequency around 1,000 kc with the oscillator output connected to the high side of the video second detector output resistor. This should give vertical bars on the scanning raster as shown in Fig. 549.

Fig. 560

(2) Apply to the grid through a coupling condenser of the last picture i-f stage, a 400c modulated i-f signal of around 11 mc from a test oscillator. The sound modulation will appear as a series of black and white horizontal bars or stripes on the Kinescope screen if all circuits are OK.

Blurring of Picture Due to Insufficient High Frequency Response

Advancing the contrast control too far produces results similar to this.



By going toward the first detector in successive stages, the faulty stage may be located and circuit checked. The output of the test oscillator should be reduced as successive stages are checked to prevent overload.

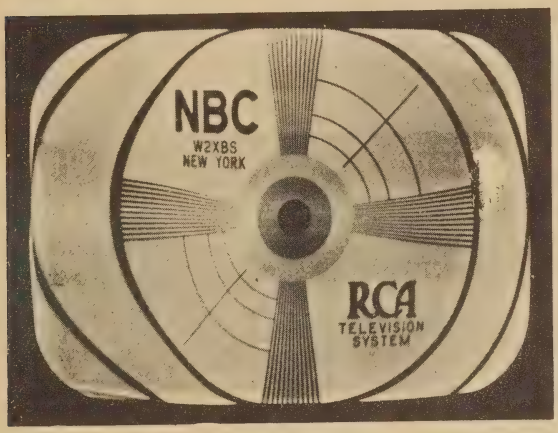


Fig. 561

NO SYNCHRONIZATION

Assuming a proper signal at the receiver input, loss of synchronization may be due to—

(1) Defective synchronizing separator or defective amplifier tube.

(2) Circuit defect such as loss of supply voltages, open circuit, etc.

UNSTABLE SYNCHRONIZATION

A slight "tearing" at the top of the picture such as shown in Fig. 552, may indicate a microphonic or

noisy tube or loose connection in the r-f or i-f system, the horizontal synchronizing separator or synchronizing amplifier circuits.

A "bounce" in the picture may indicate unstable vertical synchronization due to a circuit defect or microphonic tube.

Unstable synchronization also may, of course, be due to loose antenna or lead-in connection. Momentary loss of synchronization may be due to line voltage surges caused by switch operation.

Severe noise pulses or loss of interlacing with resulting lack of detail may be caused by improper vertical hold control adjustment. Fig. 553 illustrates the condition of no interlacing. The line structure becomes easily visible (see Fig. 553) as instead of 441 lines only 220½ lines scan the screen.

Defects in the vertical integrating filter may cause unstable interlacing.

Circuit defects to cause excessive coupling of the horizontal deflection circuits to the vertical circuits may cause a loss of interlacing.

Under any unstable synchronization condition, it is recommended that a telephone check be made with a receiver location known to be operating normally.

Remember under no conditions work on the high voltage circuits, without first removing the power supply cord from the power supply outlet.

HUM OR RIPPLE IN PICTURE

Excessive ripple in the picture is readily discernible as uneven illumination. Hum voltage (60c) appearing in the video amplifier is illustrated in Fig. 550 and 551 which is an exaggerated condition.

Excessive 60c ripple in the horizontal deflection circuits is illustrated in Fig. 547.

Excessive 60c ripple in the vertical deflection circuits is shown in Fig. 554.

The effect of 120 cycle ripple would appear as a

doubling of the wavy edges, dark and light bands, etc., as shown for 60 cycle ripple.

Any hum effect may be due to a circuit or tube defect. Replacing tubes and checking circuit continuity should readily locate the trouble.

VERTICAL DISTORTION

Besides the vertical linearity adjustment, the vertical discharge circuit of a condenser and resistor in series for magnetic deflection systems will cause a crowding or even over-lapping of lines at the top if resistor or condenser is defective. This is shown in Fig. 555.

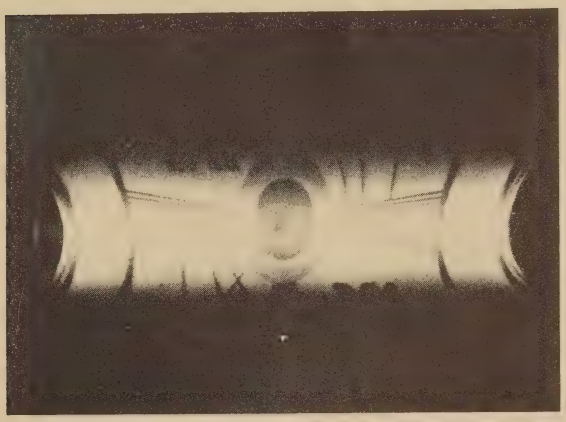


Fig. 562

In Fig. 556 is illustrated a test pattern containing transient reproduction of sections of the pattern. Such a condition may be caused by an improper alignment of the r-f oscillator, a wrong type i-f response curve or open peaking coil circuits in the video amplifier. If continuity testing of the video circuits discloses no trouble,

then the r-f oscillator and picture i-f stages will need an alignment check.

LOSS OF HIGH VIDEO FREQUENCIES

The higher video frequencies when present assure sharp reproduction of detail. The extent to which the divisions of either vertical wedge of the NBC test pattern can be clearly seen is an indication of the over-all video response.

In the normal test pattern reception of Fig. 557, divisions of the wedge can be clearly seen to the first "bull's-eye" circle. This picture was taken on a typical high quality receiver with a 12 inch Kinescope. Such a receiver has approximately linear response to 4 mc. The divisions of the wedge can be clearly seen to the first length as the bull's-eye end of the wedge represents detail as would be produced by a response of 3.5 mc.

Lower priced receivers, such as those using smaller Kinescopes, do not require as high a response as 4 mc for satisfactory results.

Hence in normal test patterns seen on these smaller receivers, the wedge divisions will be clearly seen only about two-thirds down th top wedge or two-thirds up the bottom wedge.

The loss of high video frequencies will be apparent by a blurring or a lack of sharpness in most parts of the test pattern, but more particularly by the nature of the vertical wedge. Fig. 558 indicates a serious loss of high video frequencies. Such a loss may occur due to open or shorted peaking coils in the video amplifying circuits or too narrow r-f, i-f, or antenna frequency response band.

LOSS OF LOW VIDEO FREQUENCIES

The loss of low frequencies will usually be accompanied by a phase shift of these frequencies. This results in a Smearing of the picture by the low frequency elements such as large letters. In Fig. 559 such a condition is shown.

Such a condition might be caused by a shorting-out of video amplifier load resistors or an open by-pass condenser in the plate or screen supply circuit.

An improper i-f response curve may also introduce this low frequency smear. Blurring of the horizontal wedges of the test patten indicates a loss of low video frequencies.

HORIZONTAL DISTORTION, FAILURE OF DAMPING TUBE

Receivers using magnetic deflection use a rectifier or damping tube to eliminate a transient condition that occurs during the return line portion of the scanning saw-tooth wave.

This tube is subjected to high inverse voltages. If it should fail the effect on the pattern may be as shown on Fig. 560.

NON-LINEAR HORIZONTAL DEFLECTION, POOR DISTRIBUTION

Any horizontal deflection circuit component such as the checking resistor in the discharge sawtooth generator circuit, etc., that may be off value or defective may lead to a non-linear condition as illustrated in Fig. 561.

More often such a condition will be caused by the horizontal output tube and this tube should first be changed.

Low line voltage or off-value output tube plate load resistors can cause poor horizontal distribution.

Since component parts of such circuits necessarily are a result of design and production economics, all resistors and capacitors have values within certain plus or minus tolerances.

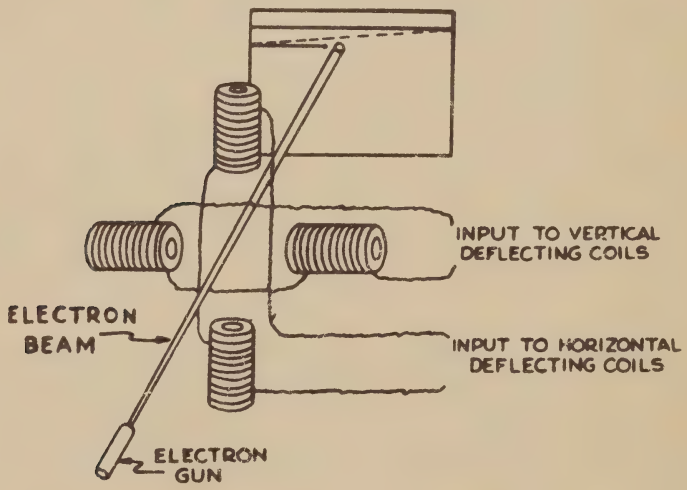
Should the tolerances add up in the wrong direction, circuit values may be changed to produce such a non-linear sawtooth deflecting voltage that horizontal or vertical crowding or stretching of picture elements may result.

OPEN HIGH VOLTAGE FILTER CONDENSERS

The general effect of an open high voltage filter condenser is similar to the combined effect of ripple in the video amplifier and ripple in the deflection circuits.

Fig. 562 illustrates the worst possible condition in that both high voltage fileter condensers were open.

All work on the high voltage circuits (up to 7,-500 volts) should be performed with the power off. This can be done by removing the power supply cord from the power supply outlet. Always discharge the high voltage condensers by connecting to ground while working on the receiver.



Action of Deflection Coils on Scanning Beam

Achromatic Lens—Compound lens so devised ("corrected") as to have no chromatic aberration for two or more wave lengths (colors), and very little aberration for all other visible wave lengths.

Acoustic—(1) Science of sound. (2) Acoustics of an enclosure: refers to hearing conditions within the enclosure, due to reflections and absorptions of sound.

A-C Pick-Up—Undesirable sound in the recording system.

A. F.—Abbreviation for audio frequency.

All Bottom—Sound in which low frequencies predominate.

All Top—Sound in which high frequencies predominate.

Ampere-Hour—Quantity of electricity equal to that carried by a one-ampere current in one hour. Equals 3,600 coulombs.

Amplifier—A device for increasing the amplitude of electric current, voltage, and/or power, through the control by the input power of a larger amount of power supplied by a local source to the output circuit. Specifically, (1) a vacuum tube used for this purpose; (2) the whole circuit of which such tube is the essential element.

Amplitude—The maximum height, or maximum depth, of a wave, measured from its base line or middle position. One-half the distance through which each part of the medium carrying the wave will vibrate from the time a crest passes to the time the next trough passes. The energy contained in a wave varies as the square of the amplitude of the wave.

Aspect Ratio—The Aspect Ratio of a frame is the numerical ratio of the frame width to frame height.

Audio—(Latin, "I hear")—Pertaining to the transmission of sound.

Automatic Brightness Control—Automatic Brightness Control is a device for automatically controlling the average illumination of the reproduced image.

Automatic Volume Control—A self-acting device which maintains the output constant within relatively narrow limits while the input voltage varies over a wide range.

Back Focal Length—The distance from the back of the lens to the film in the gate while the image is in focus on the screen.

Back-Focus—Distance from the principal focus of a lens (behind the lens) to its nearest face.

Backlash—"Play" or looseness of a screw or bolt in its fitting.

Band-Pass Filter—A filter designed to pass currents of frequencies within a continuous band limited by an upper and a lower critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies outside of that band.

Beats—Vibrations produced by interference between two or more wave lengths.

Bel—Equals ten decibels.

Binagural—Pertaining to both ears.

Blanket, Mike—See microphone blanket.

Blanking Pulse—Pulses produced during the return time of the cathode-ray beam to "blank out" the undesirable signals produced by the return lines in both the Iconoscope and Kinescope. Sometimes referred to as the "pedestal."

Brightness Control—Brightness Control is the receiver control which varies the average illumination of the reproduced image.

Capacitance—The measure of the quantity of electricity a condenser can hold. It equals the quantity stored divided by the voltage (pressure) storing it.

Capacity, Carrying—Current a conductor can carry without becoming overheated.

Carrier—A term broadly used to designate carrier wave, carrier current, or carrier voltage.

Carrier Frequency—The frequency of a carrier wave.

Characteristic Curve—Graph showing the essential features of the performance of a photoelectric cell, vacuum tube, photographic emulsion, or other piece of apparatus. For a film, the curve shows how transmission, or density, varies with exposure.

Choke Coil—Coil of wire wound on an iron core and thus possessing high inductance.

Chromatic—Relating to color.

Chromatic Aberration—The production of color fringes in the image formed when white light is passed through a lens, due to the fact that the lens bends the light rays of different colors by slightly different amounts.

Coaxial Cable—Special telephone cable suitable for conveying television signals.

Condenser, Air—Condenser in which the dielectric (insulator) is air.

Condenser, Paper—Condenser in which the dielectric (insulator) is paraffin paper.

Condenser, Stopping—Condenser used to block flow of d c in a circuit.

Condenser, Variable—Condenser whose capacitance can be varied.

Contrast Control—A knob on the receiver for adjusting the range of brightness between highlights and shadows in a picture.

Cycle—One complete set of the recurrent values of a periodic phenomenon.

Damping—(1) Gradual steady decrease of wave amplitude, and consequent steady decrease of volume of sound or of electric waves. (2) Removal of echoes or reverberation in a set by use of sound-absorbing materials.

D.C. Transmission—D.C. Transmission means the transmission of a television signal with the direct current component represented in the picture signal.

Decibel—Unit of gain and loss of energy, intensity, loudness. Equal to ten times the logarithm (to the base 10) of the ratio I/I, where I is final intensity and I is initial intensity in a transmitting system, or (when the decibel is used as an absolute unit) I is a standard intensity.

Other names and abbreviations are db, SU, sensation unit, TU, transmission unit. Note: the logarithm of 2 is 0.3 very nearly, therefore intensity is doubled for each gain of 3 db.

Depth of Field—The range of object distances within which objects are in satisfactory sharp focus in a photograph.

Depth of Focus—(1) Same as depth of field. (2) The range through which a photographic plate can be moved forward and backward with respect to the lens while maintaining satisfactorily sharp focus on an object at a given distance.

Distortion—A change in wave form occurring in a transducer or transmission medium when the output wave form is not a faithful

reproduction of the input wave form.

Electrode—Terminal of an electric device such as a cell or vacuum tube.

Electrolyte—Liquid conductor of electricity, as in a battery.

Electron—Unit of negative electricity, and smallest particle of matter, next to the proton. Radius, about 2×10^{-13} cm. (i.e., 0.000.000.000.-000,2 cm.). Mass, 9×10^{-28} gram. Negative charge, 1.6×10^{-19} coulomb.

Electron Emission—The liberation of electrons from an electrode into the surrounding space. In a vacuum tube it is the rate at which the electrons are emitted from a cathode. This is ordinarily measured as the current carried by the electrons under the influence of a voltage sufficient to draw away all the electrons.

Energy Density—Quantity of energy contained in a given volume, divided by the volume.

Erg—Unit of work or energy in the metric system. Approximately 13,560,000 ergs equal one foot-pound of work.

Exciter Lamp—Light source used in reproducing sound from film.

Fidelity—The degree to which a system, or a portion of a system, accurately reproduces at its output the signal which is impressed upon it.

Field Frequency—Field Frequency is the number of times per second the frame area is fractionally scanned in interlaced scanning.

Fileter, Band-Pass—A filter designed to pass currents of frequencies within a continuous band limited by an upper and a lower critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies outside of that band.

Filter, High-Pass—A filter designed to pass currents of all frequencies above a critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies below this critical frequency.

Filter, Low-Pass—A filter designed to pass currents of all frequencies below a critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies below this critical frequency.

Focus—Adjustment of spot definition.

Frame—One complete picture. Thirty of these are shown in one second on a television screen.

Framing Control—A knob or knobs on the receiver for centering and adjusting the height and width of pictures.

Frame Frequency—Frame Frequency is the number of times per second the picture area is completely scanned.

Fundamental Frequency—The lowest component frequency of a periodic wave or quantity.

Gain Control—Device for varying the gain of an amplifier.

Galavanometer — An instrument for measuring electric current strength (or for detecting a small current, and determining its direction), generally by the deflection of a needle due to the magnetic field caused by the current.

Galvanometer, String—Utilizes a conducting wire or ribbon vibrating in a strong magnetic field according to the variations of the conducted current.

Ghost—An unwanted image appearing in a television picture as a result of signal reflection.

Grid Leak—Very high, non-inductive resistance, usually connected across a condenser in the grid circuit of a three-electrode vacuum tube, to stabilize the action of the condenser (in making the tube more efficient) by permitting excess charge to leak off.

Harmonic—A component of a periodic quantity having a frequency which is an integral multiple of the fundamental frequency. For example, a component the frequency of which is twice the fundamental frequency is called the second harmonic.

Horizontal Centering—Adjustment of the picture position in the horizontal direction.

Horizontal Hold—Adjustment of the free-running period of the horizontal oscillator.

Height—Adjustment of the picture size in the vertical direction.

Iconoscope—A type of electronic cathode-ray pickup tube which has been developed by RCA.
It serves the dual purpose of analyzing the visible picture projected on its mosaic into elements and produces electrical impulses for each of these picture elements.

Image—The effect produced by a definite aggregation of light rays coming dirctly or indirectly from an object or group of objects, and determined in form and color by two factors; the original object, and the mediums which have transmitted the light rays. A mirror forms an image on any suitably placed object; so does a lens, so does any optical system. Images may be larger or smaller than the object; may be inverted or not; and may or may not have various distortions. The human eye can see by virtue of the fact that the eye is an optical system which forms a real image on the retina. (This image is actually inverted, but is re-inverted by the brain in the process of interpretation.)

Image, Aerial—Image in space formed by an optical system.

Image, Real—Image through which the light rays actually pass, such as the image formed by a lens on the ground glass or photographing film of a camera. Real images are always inverted.

Image, Virtual—An image through which the light rays do not actually pass, e.g., the image formed by an ordinary plane mirror behand the mirror, the rays being reflected from the mirror in such a manner that they appear to the eye to come from behind the mirror. Such an image cannot be shown on a groundglass screen as can a real image, nor can it by itself produce a photographic action. (You can photograph the virtual image formed by a mirror, but you have to use an additional optical system—you cannot simply put the film behind the mirror where the visual image is. Virtual images are never inverted.

Interference—Disturbance of reception due to strays, undesired signals, or other causes; also, that which produces the disturbance.

Interlacing—A technique of dividing each picture into two sets of lines to eliminate flicker.

Kinescope—A type of electronic cathode-ray receiver tube which has been developed by RCA. It converts electrical impulses into picture elements which are visible to the eye.

Line—A single line across a picture, containing highlights, shadow, and half-tones, 441 lines make a complete picture.

Linear—Two quantities are said to have a linear relation when multiplying one by a given factor automatically multiplies the other by the same factor. Thus, there is a linear relation between the distance

a car travels and the number of times its wheels revolve.

Linearity Control—Adjustments of scanning wave shapes. May be qualified by the adjectives, 'Top,' 'Bottom,' 'Right,' 'Left.'

Logarithmic Relation—If multiplying one quantity by a given factor automatically multiplies another by the logarithm of that factor, the relation between the two quantities is logarithmic.

Long-Shot—A scene photographed utilizing the entire angle of the view of the camera lens, with the lens focused for objects at practically infinite distance. Long-shots include scenes which are general in their character—scenes of wide scope; the general assemble; the full room with all characters included; full length exterior scenes; landscapes with characters included; etc. For long-shots, lenses of short focus—from two inches to about one inch—are generally used.

Lumen—Unit of luminous flux. A source, whose luminous intensity in all directions is one candle power, emits 4 lumens.

Luminosity Curve—For any light source, a curve showing the variation of emitted light with wave length (color) along the spectrum.

Luminous Flux—Equals amount of luminous energy flowing per unit time. Luminous energy represents light energy evaluated according to the luminous sensation produced in the human eye.

Luminous Intensity—The luminous intensity of a light source in any direction, is the luminous flux per steradian (unit solid angle) in that direction.

Megacycle—When used as a unit of frequency, is a million cycles per second.

Modulation—Modulation is the process in which the amplitude, frequency, or phase of a wave is varied in accordance with a signal, or the result of the process.

Mosaic—Photo-sensitive plate mounted in the Iconoscope. The picture is imaged upon it and scanned by electron gun.

Negative Transmission (Modulation)—Negative Transmission (Modulation) occurs when a decrease in initial light intensity causes an increase in the radiated power.

Neon Lamp—Small bulb containing no matter except a little neon gas and two electrodes. When current is passed through this, the tube glows with a red light. It is very sensitive to small changes in current, and varies its brightness accordingly.

Optical Axis—Straight line through the centers of the light source, lenses, diaphragm, etc., of an optical system, to which their planes are in general perpendicular.

Ordinal Response or Ordinal Relation—Said to occur when increasing one quantity automatically increases another, and decreasing the one automatically decreases the other. An ordinal relation is not necessarily linear.

Oscillating Circuit—Electric circuit which offers very little opposition to the establishment of an oscillating current of the frequency to which the circuit is tuned.

Panning—A horizontal sweep of the camera. (From "panorama.")

Photoelectrons—Electrons liberated by light when the photoelectric effect takes place.

Photometer—Any device for measuring light intensity.

Polarization—The particular property of an antenna system which determines its radiation characteristics.
i. e.—Vertical or horizontal polarization.

Positive Transmission (Modulation)—Positive Transmission (Modulation) occurs when an increase in initial light intensity causes an increase in the radiated power.

Potentiometer—Device controlling or measuring the electromotive force (voltage) across one or more circuits, by placing each of these in parallel with a variable part of a fixed resistance.

Power—Rate of doing work or producing energy. Equals work or energy divided by time taken to produce it.

Progressive Scanning—Progressive Scanning is that in which the scanning lines trace one dimension substantially parallel to a side of the frame in which successively traced lines are adjacent.

Radio Channel—A band of frequencies or wave lengths of a width sufficient to permit its use for radio communication. The width of a channel depends upon the type of transmission.

Reactance—An electric circuit opposes a varying current not only by virtue of resistance, but also by virtue of its tendency to oppose the variation in the current. Reactance is a measure of this latter tendency. It involves no loss of energy, but simply causes a displacement in time between variations in voltage and variation in current. Reactance is of two sorts: inductive reactance, due to inductance; and capacitative reactance, due to changes of electric charge in any condensers which are in the circuit. The greater the frequency of a c the greater the inductive reactance of the circuit, and the less the capacitative reactance.

Reactor—High-inductance coil.

Rectilinear Lens—Lens which produces undistorted images of parallel lines.

Resonance—Response of a vibrating body, or of an electric circuit, to vibrations impressed upon it, particularly to those which have the same frequency as a natural frequency of the body or circuit. Vibrations at such a frequency tend to have a greater amplitude than vibrations at any other frequency; consequently the body or circuit re-radiates a comparatively large amount of energy at that frequency, and re-enforces any waves (sound or electrical, as the case may be) of that frequency which reach it.

Return Line—Trace of the cathode-ray beam in returning from bottom to top of the picture. (Return trace from right to left between lines usually not visible.)

Reverberation—Persistence of sound in an enclosed space, due to reflection from the walls.

Reverberation, Time Of—Time required for a reverberating sound to die away to one one-millionth of the intensity of the original sound.

Sawtooth—A wave of electric current or voltage employed in scanning.

Scanning—Scanning is the process of analyzing successively, according to a predetermined method, the light values of picture elements constituting the total picture area.

Scanning Line—A Scanning Line is a single continuous narrow strip which is determined by the process of scanning.

Side-Bands—The bands of frequencies, one on either side of the carrier frequency produced by the process of modulation.

Signal—The intelligence, message or effect conveyed in communication.

Spectrum—Any arrangement of waves in the order of their frequencies. For light waves, the order of the spectrum, beginning with the highest frequencies, is ultra-violet, violet, indigo, blue, green, yellow, orange, infra-red. If these were taken in the order of wave lengths, beginning with the highest, the order would be reversed from that just given.

Spot—The visible spot of light formed by the impact of the electron beam on the screen as it scans the picture.

Spottiness—Spottiness is the effect of a television picture resulting from the variation of the instantaneous light value of the reproduced image due to electrical disturbances between the scanning and reproducing devices.

Television—Television is the electrical transmission and reception of transient visual images.

Tilting—A vertical sweep of the camera.

Vertical Centering—Adjustment of the picture position in the vertical direction.

Vertical Hold—Adjustment of the free-running period of the vertical oscillator.

Vestigial-Side-Band Transmitter—A Vestigial-Side-Band Transmitter is one in which the one side band and a portion of the other are intentionally transmitted.

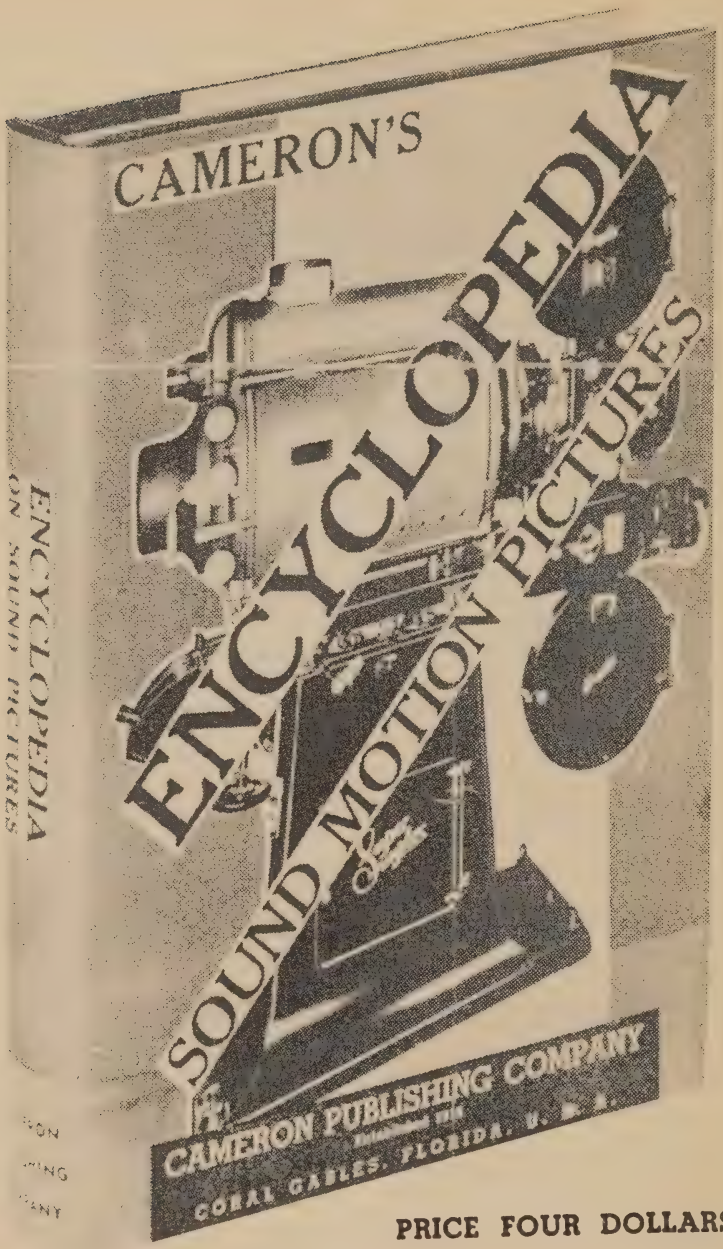
Video Frequency—The Video (Latin, "I see") Frequency is the frequency of the voltage resulting from television scanning.

Wave Front—Crest of an advancing wave.

Wave Length—Distance between crests along a wave.

Width—Adjustment of the picture size in the horizontal direction.

Yoke—Produces magnetic deflection of an Iconoscope or Kinescope when supplied with sawtooth currents of proper voltage and phase.



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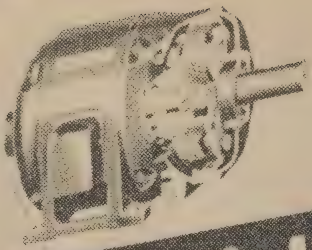

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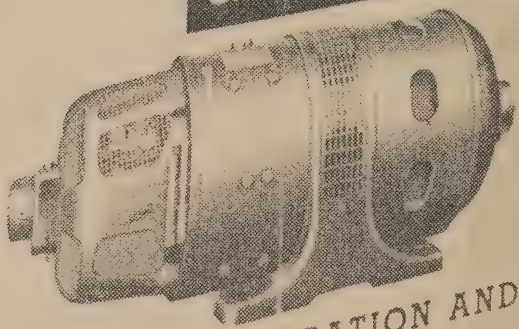

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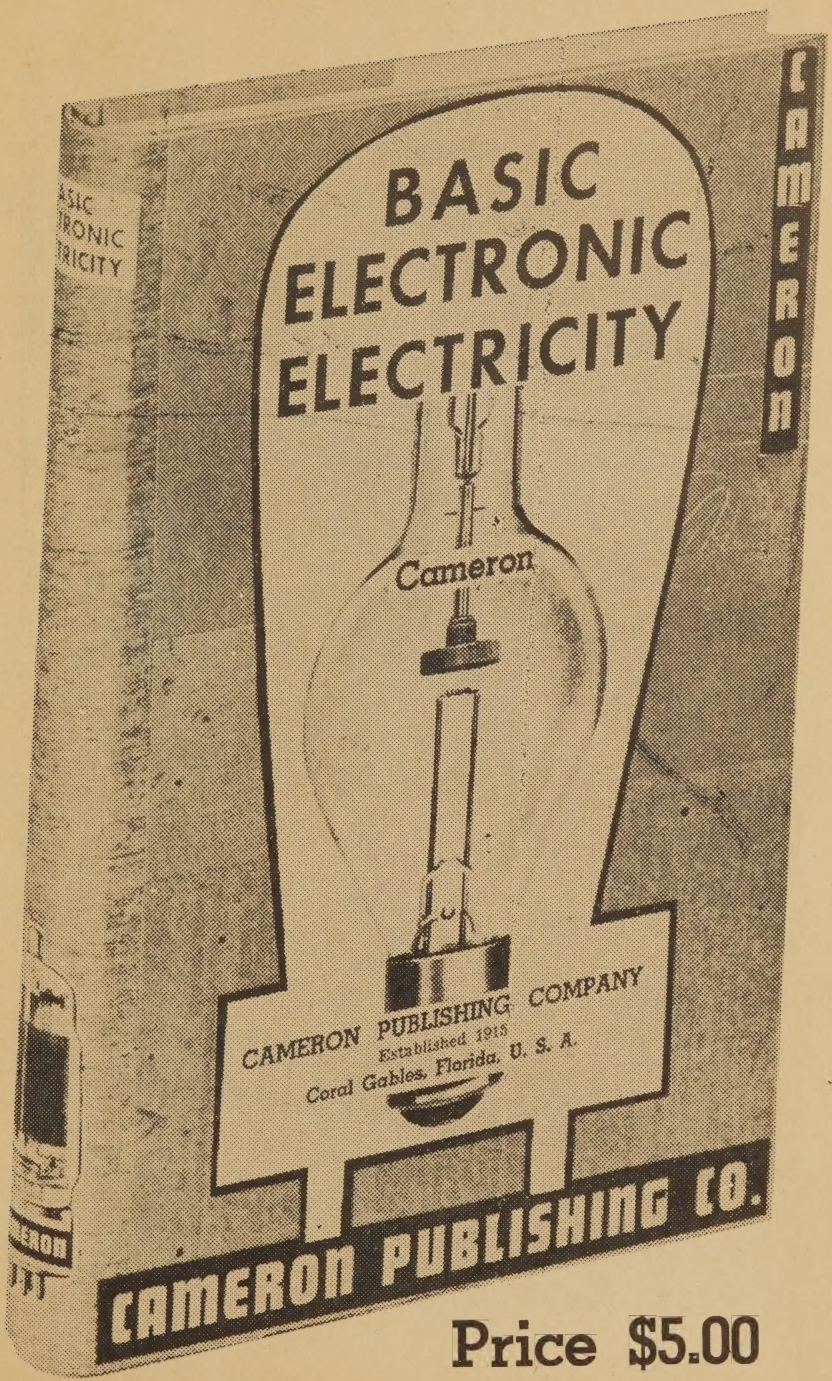
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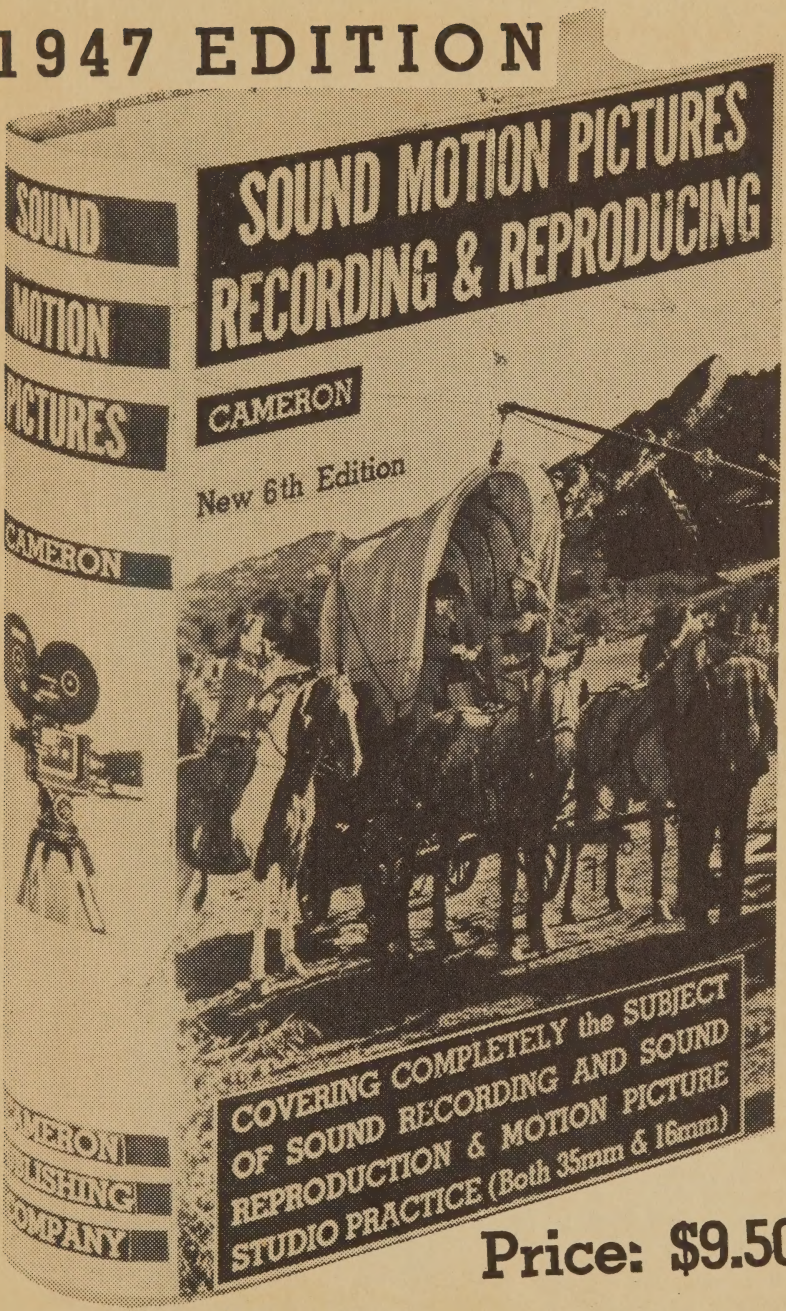
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